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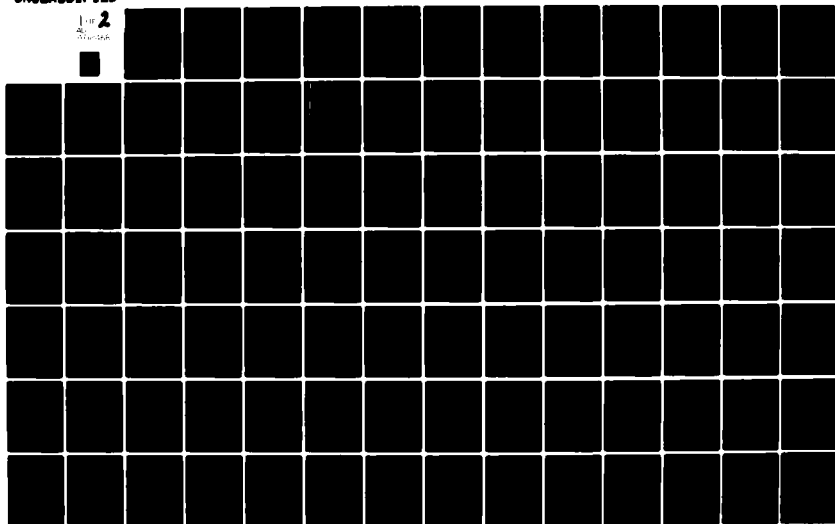
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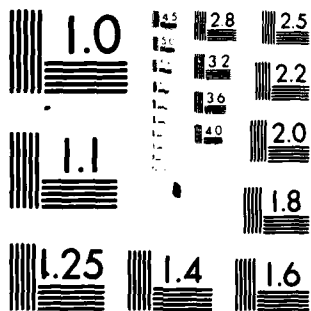
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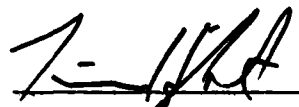
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DEVELOPMENT OF A STRAIN RATE DEPENDENT LONG BONE INJURY
CRITERION FOR USE WITH THE ATB MODEL

FINAL REPORT

CONTRACT AFOSR-81-0062



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ABSTRACT

An improved version of a previously reported long bone injury criterion has been developed. This new criterion was based on fitting the Ramberg-Osgood equation, through optimization techniques, to existing stress-strain-strain rate curves for compact bone and using this equation to solve for the strain at a time step given the current stress and the strain from the previous time. Refinements have also been made to the geometric modeling of the bones where adequate data existed. When coupled with the (ATB) model and relations between ultimate stress and strain rate, this criterion has provided an effective means of judging long bone injury potential.

I. INTRODUCTION

The Articulated Total Body (ATB) Model has been developed as a tool to predict and analyze the response of the human body to potential injury causing environments. This model has been primarily used for the analysis of vehicular crashes, and has been extremely useful in predicting gross motion of the body. The model also predicts the loads on each of the articulated joints. The USAF has been involved in the development and testing of this computer model and has applied it to the analysis of the response of pilots to ejection from jet aircraft. During these events the body is subjected to high accelerations from the ejection itself, to impacts of the limbs with each other and with the cockpit, and to "wind flail" from the high velocity wind stream which impacts the body after clearing the aircraft. It is hoped that a better understanding of these events will lead to safer designs and lower injury rates.

Despite the excellent results obtained from the ATB model, the current version does not provide the information necessary to predict whether the event will or will not cause an injury. It is therefore necessary to augment the current model by the addition of some sort of injury criterion in order for the full potential of the ATB to be realized. With this addition, the model can be used to compare different acceleration profiles, restraint systems and other variables as to their injury preventing potential. Currently these assessments must be made, in a very qualitative way, on the basis of motion of the limbs and loads in the joints.

Since the majority of serious injuries resulting from ejections are bone fractures, it is of particular interest to estimate the likelihood of long bone fracture. (It should be noted that a separate computer model, the Head-Spine Model,

is specifically designed to study the question of head and spine injuries, and we have consciously ignored this aspect of injury).

The research carried out under this minigrant was begun by the principal investigator during a Summer Faculty Research Program stay at WPAFB. The major objectives of that research program were to establish a simplified injury criterion for bone and to implement that criterion in a computer program (BREAK) compatible with the existing ATB. Due to the constraints of such a short time period (10 weeks), the project was necessarily restricted to a rather narrow scope. Within these constraints the objectives were accomplished. A detailed report of this project can be found in the Final Report submitted to SCEE, and published as a technical report by AFAMRL (1), but the significant developments will be summarized here.

Injury criteria reported in the literature have focused on two distinct approaches - "experimental" and "analytical". The experimental approach comes largely from the automobile industry and involves the experimental determination of loads which, under simulated crash tests, cause injury to cadavers. For long bones this is restricted to the Femur Injury Criterion which is a measure of the axial load applied to the shaft of the femur which causes fracture. The current Federal Standard is 1700 lb force without any loading rate dependence. A number of authors have suggested different criteria with loading rate sensitivity (2,3). Even so, the basic fault of these criteria is their specificity - they say nothing about other long bones or other loading conditions. This type of criterion was therefore inappropriate to a study of ejection seat injuries.

The alternate type of injury criterion is based on the analytic approach using the material and geometric properties of the bone and the calculated stresses. This approach has the advantage of being applicable to any loading situation if the properties of the bone are known. This was the approach taken.

The material properties of bone are highly variable, depend on a large number of parameters and are time dependent (4,5,6). In order to accurately model the behavior of bone, consistent data including complete strain rate dependent stress strain curves are needed for human bone. The data which most nearly fulfilled these criteria was the work of McElhaney (7) which was for embalmed human bone in compression. His results indicated the following relation between ultimate stress (σ) and strain rate ($\dot{\epsilon}$)

$$\sigma = 4200 \log \dot{\epsilon} + 33000. \quad (1)$$

This equation, after modifications, became the basis for the injury criteria developed. Two major changes to this equation were made - the strain rate dependency was replaced by a stress rate dependence, and the constant term was modified to bring the results in line with published static results for fresh human compact bone. The rate modification was accomplished by first finding a relation between elastic modulus and strain rate, and then differentiating the elastic stress strain relation with respect to time for a constant strain rate. The second modification was based on $\dot{\epsilon} = .001$ as a static strain rate and was straightforward. The resulting equation for compression (and in psi units) is

$$\sigma = 3936 \log \dot{\epsilon} + 12000 \quad (2)$$

Similar expressions were generated for tension and shear based on the assumption that the material behavior (rate dependence) would be the same in the other modes and that only the constant offset would change. These equations formed the basis of the injury criterion models developed that summer.

An alternative to these criterion was generated using stress pulse duration, rather than stress rate, as the time variable. This alternate approach was examined because most published criteria from the auto industry are based on pulse duration.

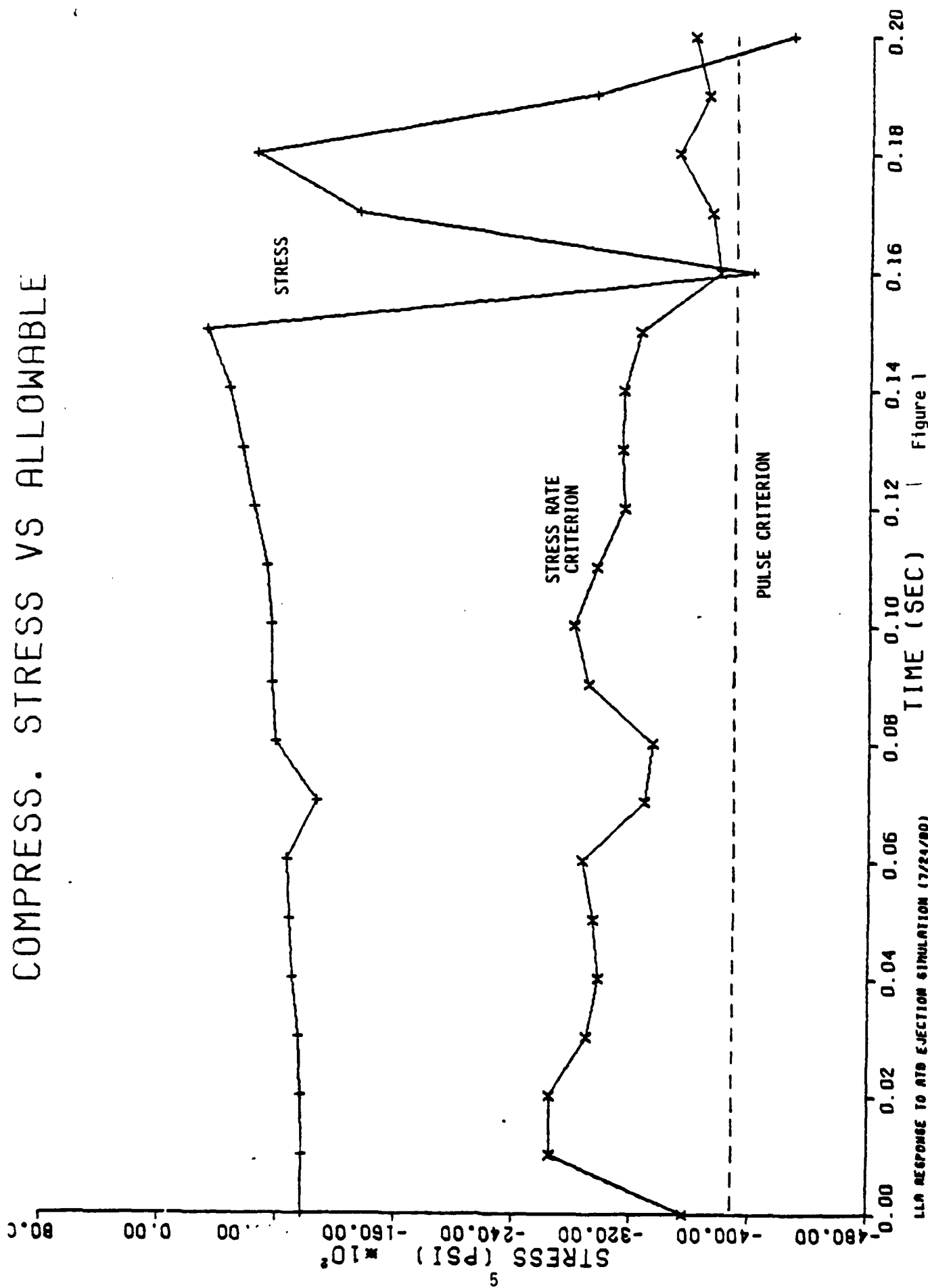
The pulse duration was approximated by assuming a sinusoidal pulse for the stress. The "pulse" criterion tended to be slightly less conservative than the stress rate criteria.

The stress calculations were based on a very simplified geometry, namely straight, uniform, isotropic hollow tubes for all the long bones. Principal stresses were then calculated at some predetermined number of sections equally spaced along the bone axis and the peak tension, compression and shear stresses were monitored. The peak stresses as a function of time for a particular limb were therefore not necessarily stresses at the same point, the position along the axis of the bone could vary with time also.

A test case was run based on an ejection simulation to demonstrate the program. Results are presented in the Technical Report mentioned above and a sample figure is reproduced here. Figure 1 shows the maximum compressive stress as a function of time for the left lower arm. There was contact at .07 secs and some high level, higher frequency loading at the elbow near the end of the data used (only the first 200 msec of the event were examined). The stress rate dependence of the allowable stress is evident as is the slightly less conservative nature of the pulse criterion. Note that the pulse criterion has only been calculated for the maximum stress pulse and hence appears as a constant.

This summarizes the state of this project at the start of the minigrant.

COMPRESS. STRESS VS ALLOWABLE



LLA RESPONSE TO AIR EJECTION SIMULATION (7/24/80)

Figure 1

II. OBJECTIVES

As outlined in the grant proposal, there were five main objectives of this investigation, and they were:

1. Improve the efficiency of the developed program, BREAK.
2. Search out and reexamine the available data base on bone material properties.
3. Develop more precise constitutive equations for bone.
4. Provide a statistical analysis of the available data.
5. Redefine the injury criteria based on the new information.

III. RESULTS

In this section each of the objectives described in the previous section will be addressed in turn, and the outcome of each investigation will be detailed.

A. The greatest problem with BREAK, as discussed in the proposal, has been the lack of compatibility between the output of the ATB Model and the input needs of BREAK. Basically the problems are ones of transformation of coordinate systems and reconstruction of contact forces from resultants. As an example, suppose that a limb contacts a panel resulting in normal and friction forces. The output of the ATB Model will include the linear and angular position, velocity and acceleration of the center of mass of the segment along with the forces and moments resulting at the joints of the segment. In addition, the resultant contact force and the point of contact will be given. For BREAK, since it calculates stress levels at a number of points along the axis of the bone, all forces must be known in local coordinates and the contact forces must be known in a vector sense, rather than in magnitude only. The reconstruction of the contact forces is a laborious task which repeats the work already done by the ATB program. In fact, all necessary information exists within the ATB program at some point during the calculations and, as proposed earlier, a file could be set up containing the appropriate information. (See program CONTACT in Appendix). Unfortunately, this has not yet been carried out. The major difficulty has been the lack of available memory on the CDC-CYBER computer system used by AFAMRL. All "non essential" data are currently eliminated during processing of the program in order to save space, and that loss currently includes the data which is needed for BREAK. Therefore the current version of BREAK (see CONTACT in Appendix) includes all of the manipulations which must be performed to transform the given data into the needed format.

Another important change to the program dealt with bone geometry. Rather than continue using uniform, hollow tubes to represent bones, we have tried to imitate some of the variations in actual bone geometry. Using the limited amount of available bone geometry data (8,9) we have been able to model variations in cross-section properties along the bone axes (for 20 to 80% of distal distance) for the femur and tibia. No data was found for the upper extremity bones. For this model the bone is assumed to be made up of a discontinuous series of short sections of uniform hollow tubes.

It was necessary to scale the available data, which appeared to be from approximately 50th percentile subjects, up to a 95th percentile man so that the bone data would coincide with the other pilot data. This was accomplished by making the assumption that, for different size bodies, the stress levels in the bones would be relatively constant. Using the body weight and limb length, relative ratios of cross-sectional area and area moment of inertia could be generated using axial compressive stress and bending stress equations. The data used, in both original and scaled form, are shown in Figures 2 and 3. See program STRESS for a complete description of the analysis, along with the calculation of stresses at various cross-sections.

B. It has been well established that the elastic and ultimate properties of compact bone are loading rate dependent (e.g. 7,10). Ultimate stress levels typically vary by a factor of two or more over a range of 5 or 6 decades of strain rates. This effect is simply too large to ignore. However, the use of ultimate stress values alone, even if they are well known, is insufficient.

The ATB model represents the body as a series of rigid, though resilient, links connected by springs. As such, for each segment the end loads and motions are well

GEOMETRIC PROPERTIES OF BONE CROSS-SECTION TIBIA

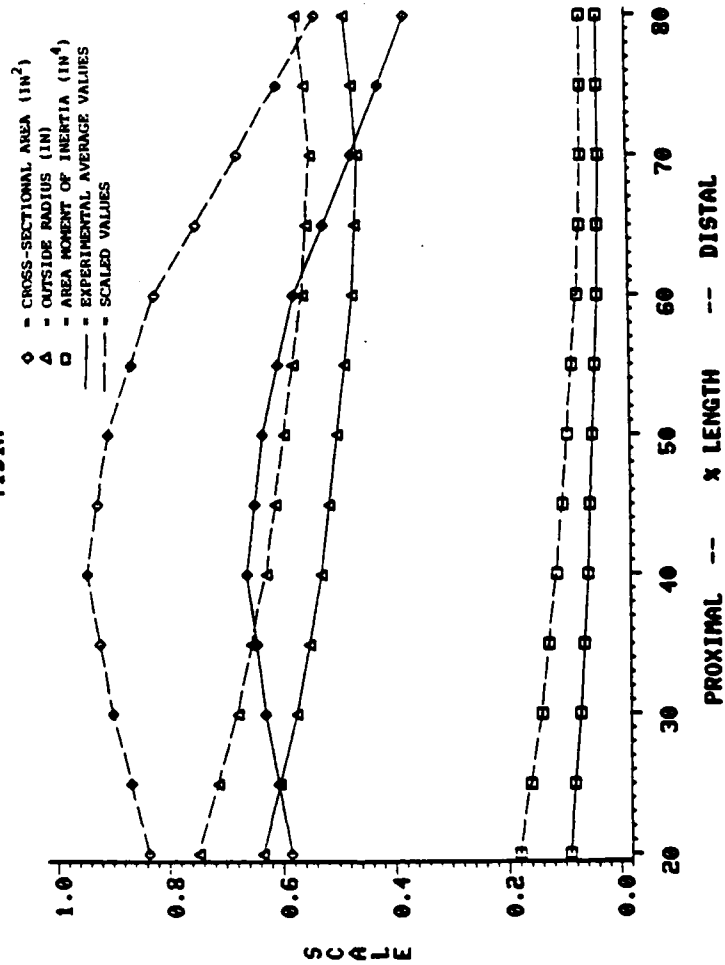


FIGURE 2

GEOMETRIC PROPERTIES OF BONE CROSS-SECTION FEMUR

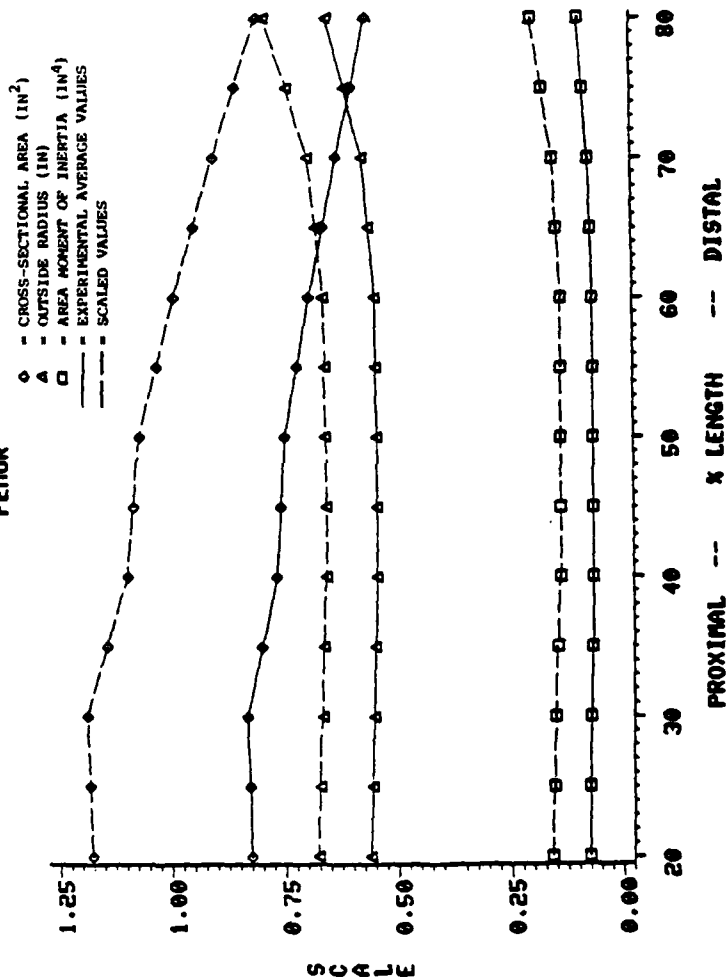


FIGURE 3

defined. These knowns, along with the bone geometries, are sufficient to describe the stress state at any timestep and at any point along the limb. The strains are then related to the stress through the theory of elasticity (for an elastic structure). For bone, the modulus of elasticity is a function of strain rate, and that function is not analytically invertible.

Three sets of stress-strain curves for various strain rates have been uncovered in the literature. McElhaney published the results of both bovine and embalmed human bone in compression using constant strain rates between 10^{-3} and 1500 sec^{-1} (7). More recently, Wood has reported on the tensile properties of fresh cranial bone for strain rates from $.003 \leq \dot{\epsilon} \leq 150 \text{ sec}^{-1}$ (11). This data is of little utility for the ATB model because Wood used very small bone samples and because cranial bone is significantly different in structure from diaphysial compact bone. Crowninshield and Pope (12) have also published results for compact bovine bone in tension over strain rates of $.00167 \leq \dot{\epsilon} \leq 250$. Their results indicate a much larger plastic strain region for longitudinal samples than do the results previously reported. However, Burstein et.al. (13) have also shown considerable plastic strain in bovine bone in tension and very little in compression. In Burstein's tests strain rates were not reported, but loading duration was between 1/10 and 1/2 sec.

The above three papers constitute a very small data set and none of the results are for fresh human long bone. Other researchers have dealt with portions of this problem, however they usually report only ultimate properties and not the full stress-strain curves. Lewis and Goldsmith (14), for example, used a split Hopkinson Bar method to measure the fracture stress of bovine bone in compression. The strain histories were pulses rather than constant strain rate. The fracture strain rates were calculated by dividing the fracture strain by the time and these rates varied

over approximately 6 orders of magnitude. These results are consistently higher than the results of McElhaney. Wright and Hayes (15) reported ultimate tensile strength for fresh bovine bone for $5.3 \times 10^{-4} \leq \dot{\epsilon} \leq 237 \text{ sec}^{-1}$. They also present two characteristic load-displacement curves, but no stress-strain data.

C. Much progress has been made in the area of establishing analytic functions which describe the relationship between stress, strain and strain rate. Using available published data and our optimizing curve fit computer program we have been able to get good fits of the data using a standard Ramberg-Osgood equation,

$$\epsilon = \frac{\sigma}{c\dot{\epsilon}^d} + a\sigma^N \dot{\epsilon}^b . \quad (3)$$

This equation is a standard equation for modeling visco elastic-plastic behavior of materials (16). Results for the three available sets of curves are shown numerically in Table 1, and graphically in Figures 4, 5, and 6. The ability of this function to fit such a wide variation of results is encouraging.

Because of the orders of magnitude variations in the strain rate, certain constants in equation (3) were extremely sensitive. For example, the constant multiplier "a" for the plastic term varied by as much as 55 orders of magnitude from author to author. It was therefore necessary to take our optimization approach (see program MYFIT in Appendix) to minimize the function F (the sum of weighted errors of data-point fits), where F is defined by equation (4).

$$F = \sum_{i=1}^M [H(\epsilon_p - \epsilon_o)]^N + r \sum_{i=1}^M <g_i>^Z \quad (4)$$

BONE TYPE	Test Mode	c	d	a	N	b
emb. human femur	C	3551	.0671	6.12×10^{-13}	6.53	-.3740
bovine (long.)	T	1694	.0180	3.71×10^{-68}	45.3	-2.336
cranial compact	T	2200	.0567	3.68×10^{-12}	7.66	-.4127

Table 1 (for stress in ksi)

STRESS - STRAIN CURVES

EMBALMED HUMAN FEMUR : COMPRESSION (MCELHANEY)

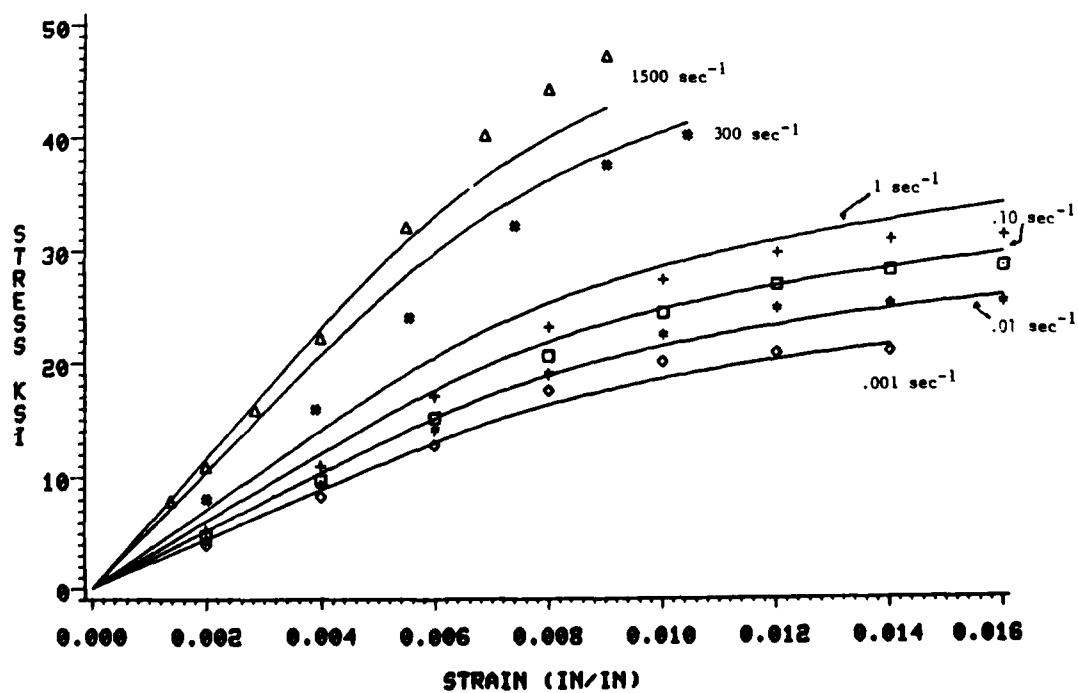


FIGURE 4

STRESS - STRAIN CURVES

BOVINE : TENSION (CROWNSHIELD & POPE)
LONGITUDINAL

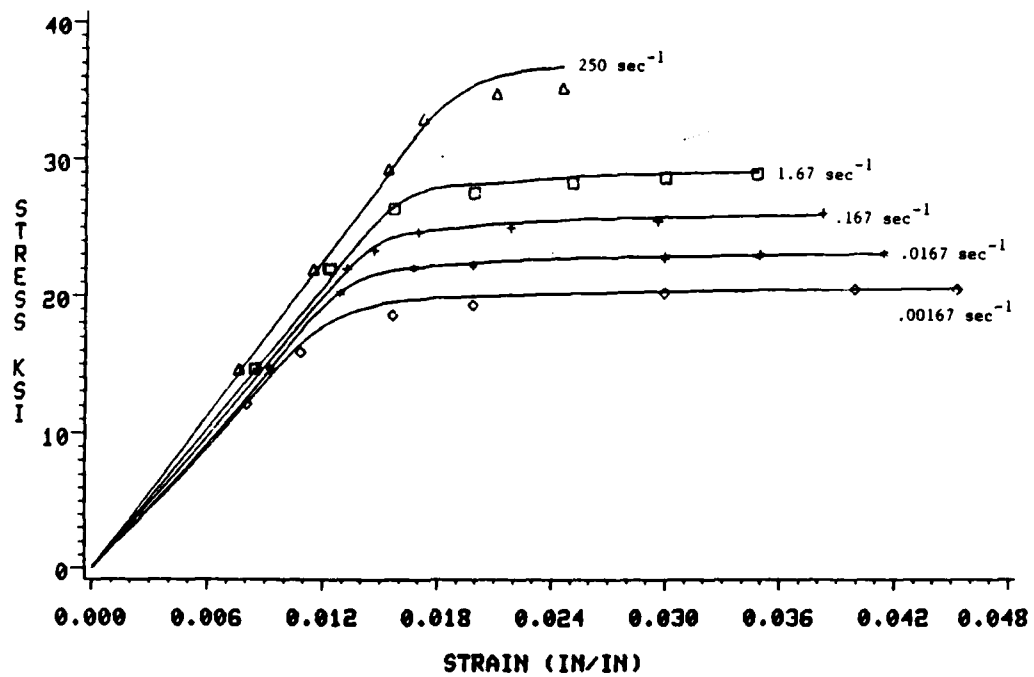


FIGURE 5

STRESS - STRAIN CURVES

CRANIAL COMPACT BONE : TENSION (WOOD)

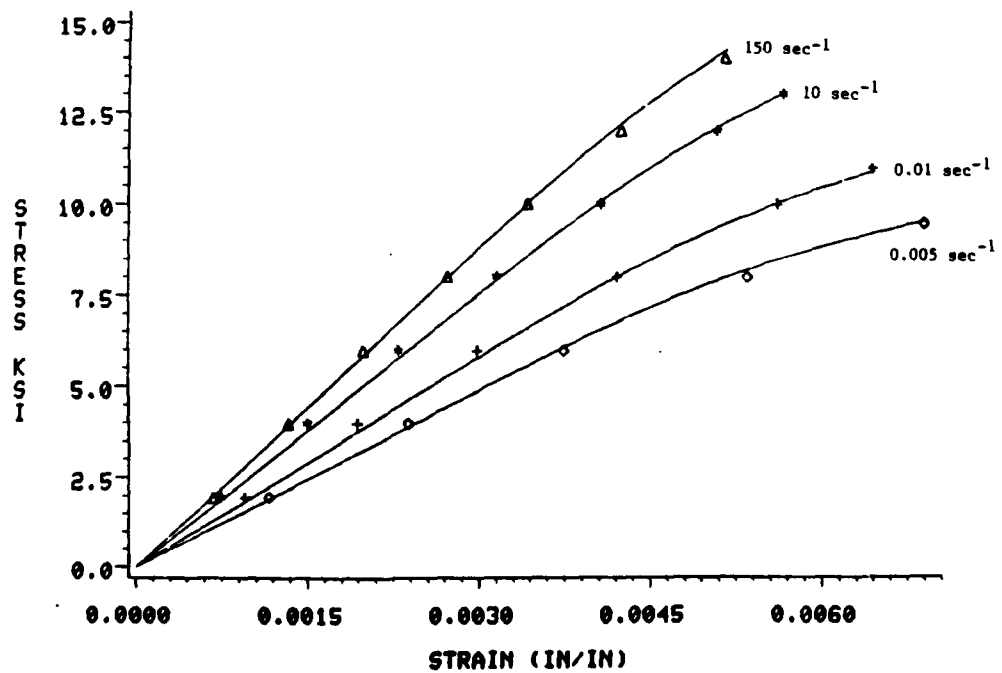


FIGURE 6

and where

- M = the number of experimentally observed points of $(\sigma, \epsilon, \dot{\epsilon})$
- ϵ_p = strain predicted by curve
- ϵ_o = strain observed by experiment
- r, H = constant multipliers for weighting
- N, z = constant powers for weighting
- $\langle g_i \rangle$ = exterior penalty function for weighting

The objective function F is minimized in each of the five coordinate directions (a, b, N, d, c) using a combination of golden section search and parabolic interpolation methods (17). The resultant coordinates are the coefficients of the equation that best fits the set of observed data.

The results of the optimization process are the curves shown in Figures 4, 5 and 6. It can be seen that there is excellent agreement between most of the predicted and experimental results. The largest variations occur in the very high strain rate tests of McElhaney. Forcing the function to try and fit the 1500 sec^{-1} data tends to also skew the rest of the curves. As an experiment, the 1500 sec^{-1} data was removed from the sample population and the curves refit to the remaining data. This trial showed a very good correlation with the remaining data and a high prediction at 1500 sec^{-1} . As this is the only data available at this high a strain rate it is difficult to draw any conclusions about this response.

D. It is obvious from the previous section that no meaningful statistical analysis can be performed on the meager amount of available data. However, it is interesting to compare the various results and this is shown in Figures 7, 8, 9 and 10. These figures show predicted stress-strain curves at a given strain rate based on various authors' results. Be aware first of all that these curves, except

STRESS - STRAIN CURVES

STRAIN RATE = 100 / SEC

LEGEND

- 1 : human femur (embalmed) - compression
- McElhaney
- 2 : cranial compact (fresh) - tension
- Wood
- 3 : cranial compact (fresh) - tension
- Wood VA74
- 4 : bovine - tension (longitudinal)
- Crowninshield & Pope

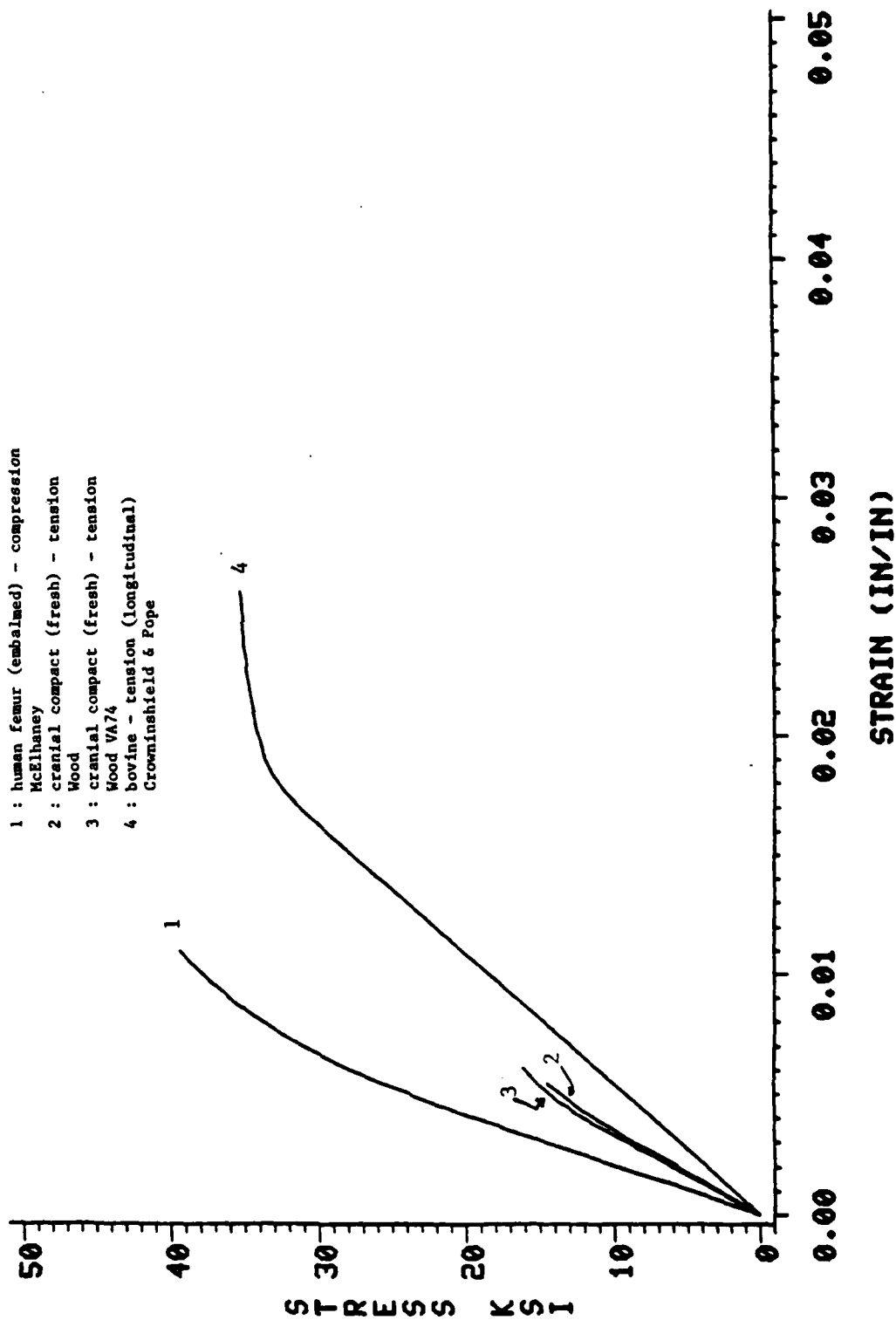


FIGURE 7

STRESS - STRAIN CURVES

STRAIN RATE = 1 / SEC

LEGEND

- 1 : human femur (embalmed) - compression
- 2 : McElhaney
- 3 : cranial compact (fresh) - tension
- 4 : Wood
- 5 : cranial compact (fresh) - tension
- 6 : Wood VA74
- 7 : bovine - tension (longitudinal)
- 8 : Crowninshield & Pope
- 9 : bovine - tension (transverse)
- 10 : Crowninshield & Pope

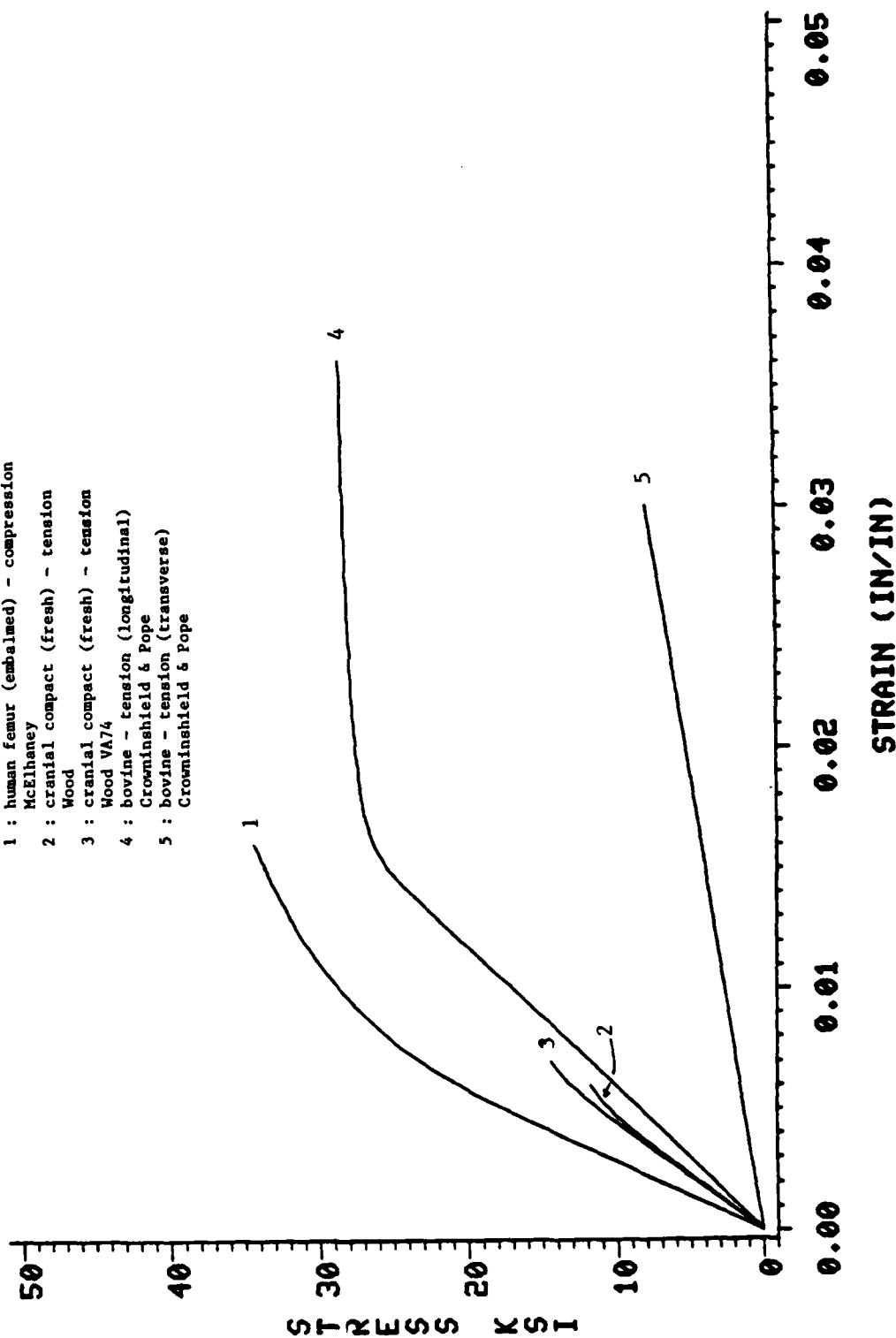


FIGURE 8

STRESS - STRAIN CURVES

STRAIN RATE = .01 / SEC

LEGEND

- 1 : human femur (embalmed) - compression
McElhaney
- 2 : cranial compact (fresh) - tension
Wood
- 3 : cranial compact (fresh) - tension
Wood VA74
- 4 : bovine - tension (longitudinal)
Crowninshield & Pope
- 5 : bovine - tension (transverse)
Crowninshield & Pope

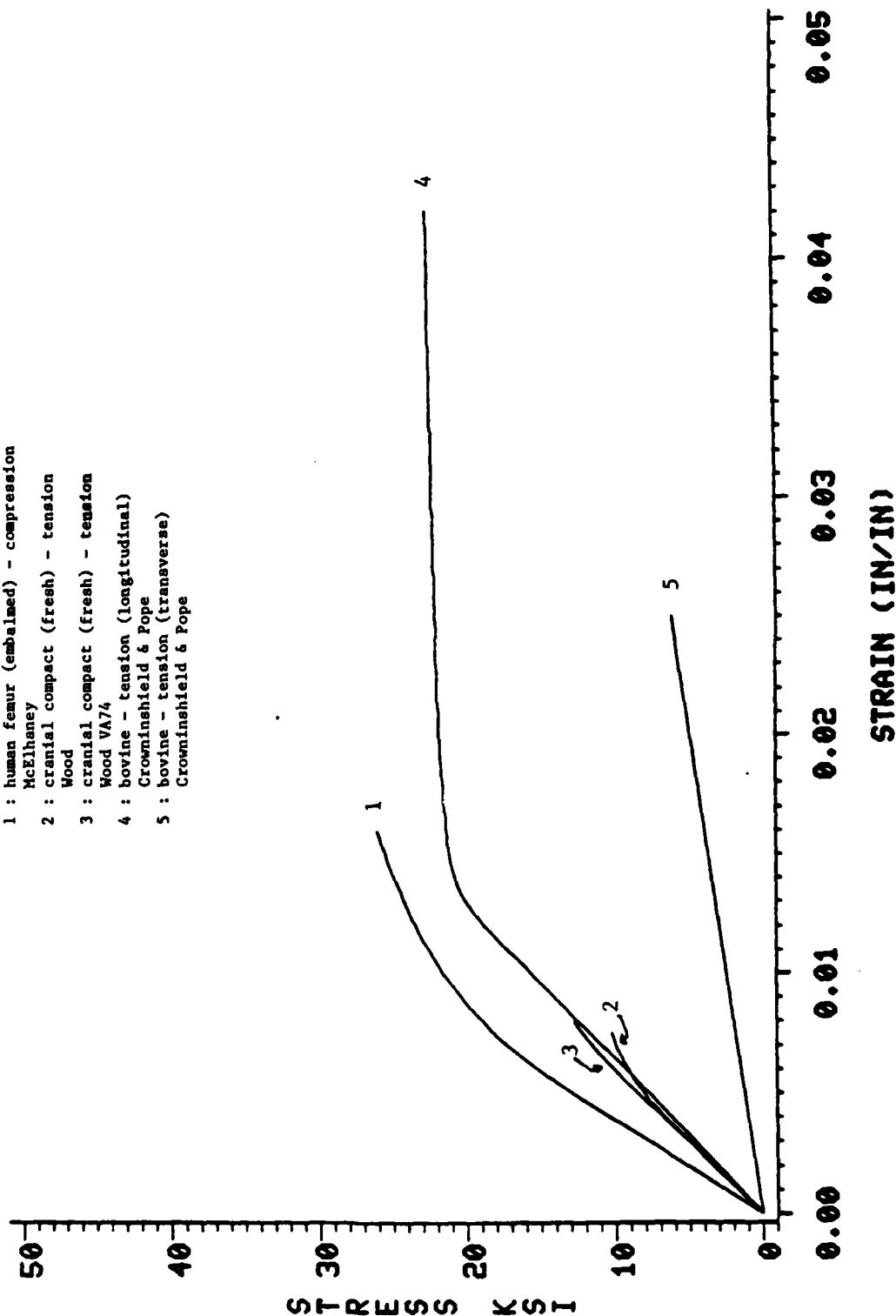


FIGURE 9

STRESS - STRAIN CURVES

STRAIN RATE = .001 / SEC

LEGEND

- 1 : human femur (embalmed) - compression
McElhaney
- 2 : cranial compact (fresh) - tension
Wood
- 3 : bovine - tension (longitudinal)
Crowninshield & Pope
- 4 : bovine - tension (transverse)
Crowninshield & Pope

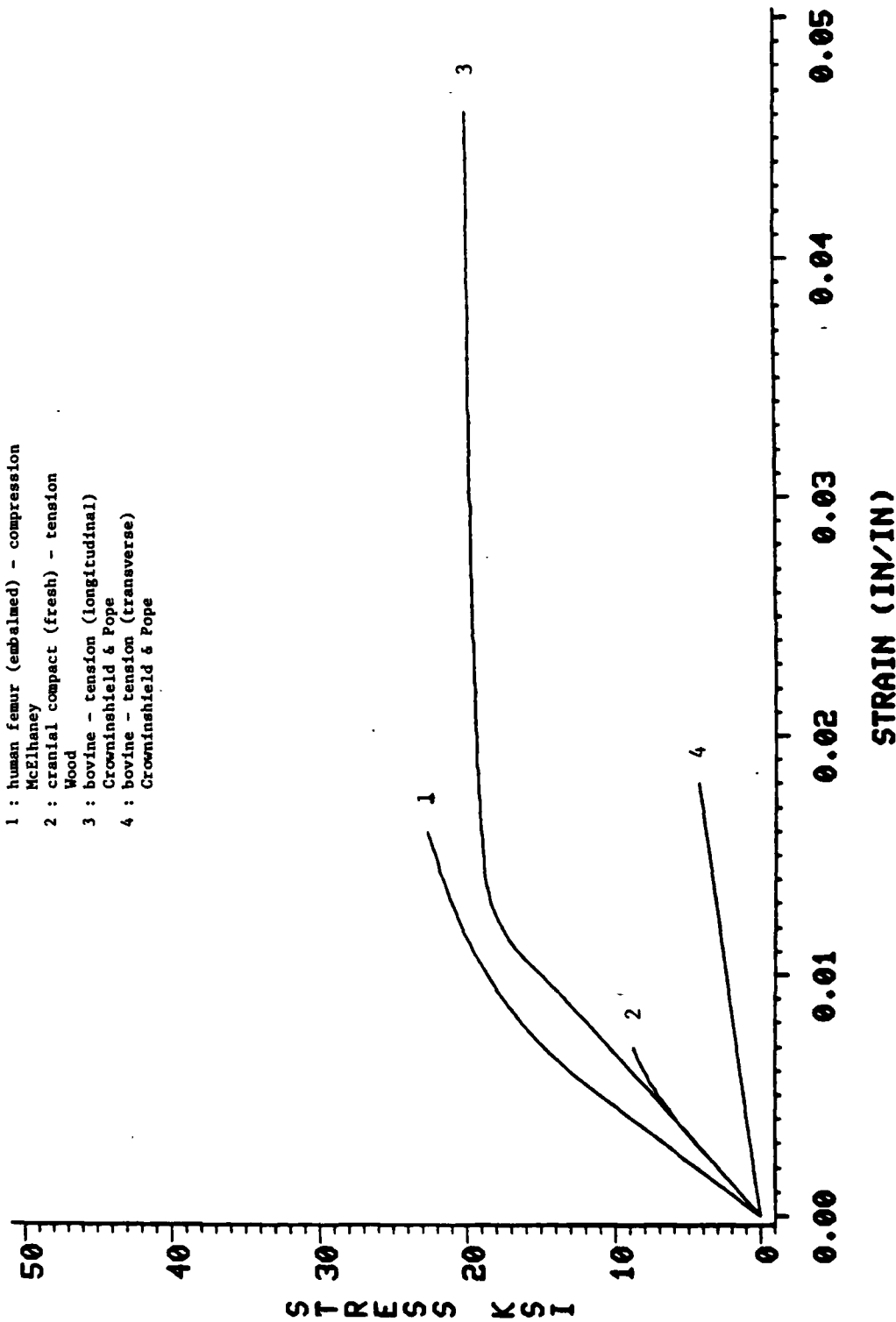


FIGURE 10

for the two by Wood, all represent different tests-embalmed human femur in compression; human cranial compact bone in tension; and bovine femur in tension for longitudinal and transverse directions. In that sense we are comparing apples to oranges. For this reason, these figures are shown only for general comparison. It had been hoped that a more direct comparison of similar data from the literature could have been made.

The cranial bone samples are generally weaker with stiffnesses bracketed by the compression results (stiffest and highest strength) and the tension results (less stiff and most plastic). Results for transverse tension samples are shown to be significantly lower in strength and stiffness. As mentioned earlier, the only significant plastic zone was found by Crowninshield and Pope for bovine bone in longitudinal tension. The results of Wood indicate that there is some consistency among data from tests on similar material and under similar conditions.

A study was carried out during the initial summer's work to assemble a small subset of this data, namely the ultimate strengths for fresh human compact bone from femurs tested statically in the longitudinal direction. The results are reproduced in Table 2. For the four modes of failure, the means and standard deviations are, respectively; tension 99.3/26/3, compression 174.4/34.2, shear 69.0/14.8 and bending 161.4/11.9, all $\times 10^6$ N/m². These figures illustrate the wide discrepancies which exist for even a narrowly defined subset of available data. The wide variations in these values could be due to a number of causes including the age and moisture content of the specimens and the test procedures utilized by the investigators.

E. The injury criteria, as first developed, were based on relationships between the ultimate stress and the strain rate (equation 1). This equation was then modified, based on a constant strain rate approximation, to yield a relation between ultimate

Table 2

Ultimate Strengths of Fresh Human Compact Bone From Femurs, Tested
Statically and Stressed in the Longitudinal Direction
($\times 10^6$ N/m²/ $\times 10^3$ psi)

<u>Tension</u>	<u>Compression</u>	<u>Shear</u>	<u>Bending</u>
122/17.7*	159/23.1*	53.1/7.7*	152/22.0 ^{&}
86.5/12.5*	193/28.0 ^{\$}	82.4/11.9*	153/22.1 [¢]
133/19.3 ^{\$}	134.5/19.5 [¢]	71.6/10.4 ^{\$}	157/22.8*
76.2/11.0 ⁺	210.9/30.6 ⁺		164/23.8*
78.9/11.4 ⁺			181/26.2*

Compiled from various sources reported in (*) Reilly and Burstein (6), (+) Evans (4), (\$) Reilly and Burstein (18), (&) Mather (19) and (¢) Vose and Kubala (20).

stress and stress rate which could be calculated directly from the available stress time histories (equation 2). This solution is rather simplistic and not entirely satisfactory. A more systematic approach based on the Ramberg-Osgood equation (equation 3) has yielded more promising results.

The elemental question is, how to calculate strain when only the stress time history is known and the relation between stress and strain is strain rate dependent? It is clear on inspection that equation (3) does not invert or separate into convenient parts, particularly since the factors b and d are, in general, not integers. The approach taken has been one of a numerical approximation based on the following equation at time step i:

$$\epsilon_i = \frac{\sigma_i}{c} \frac{1}{\left(\frac{\epsilon_i - \epsilon_{i-1}}{\Delta t}\right)^d} + a\sigma_i^N \left(\frac{\epsilon_i - \epsilon_{i-1}}{\Delta t}\right)^b \quad (5)$$

Given the stress at a time step and the strain at the previous time step, equation (5) can be solved numerically for the current strain. This solution procedure is easily initialized by assuming zero stress and strain at time = 0. Solution of this equation has been successfully accomplished and Figure 11 shows an example stress strain response to the sinusoidal stress wave shown in Figure 12. The solution displays the expected hysteresis type response.

There were a number of stumbling blocks which had to be overcome in order to achieve this solution. The second term of equation (5), which accounts for the plastic portion of the response, can have a severe destabilizing effect on the solution procedure, depending on the values of the constants and the strain rate. It was therefore necessary to use a two step method based on the Regula-Falsi technique. An initial solution was generated using only the first term of the equation to be used as a starting point. With this initial guess as a basis the final solution

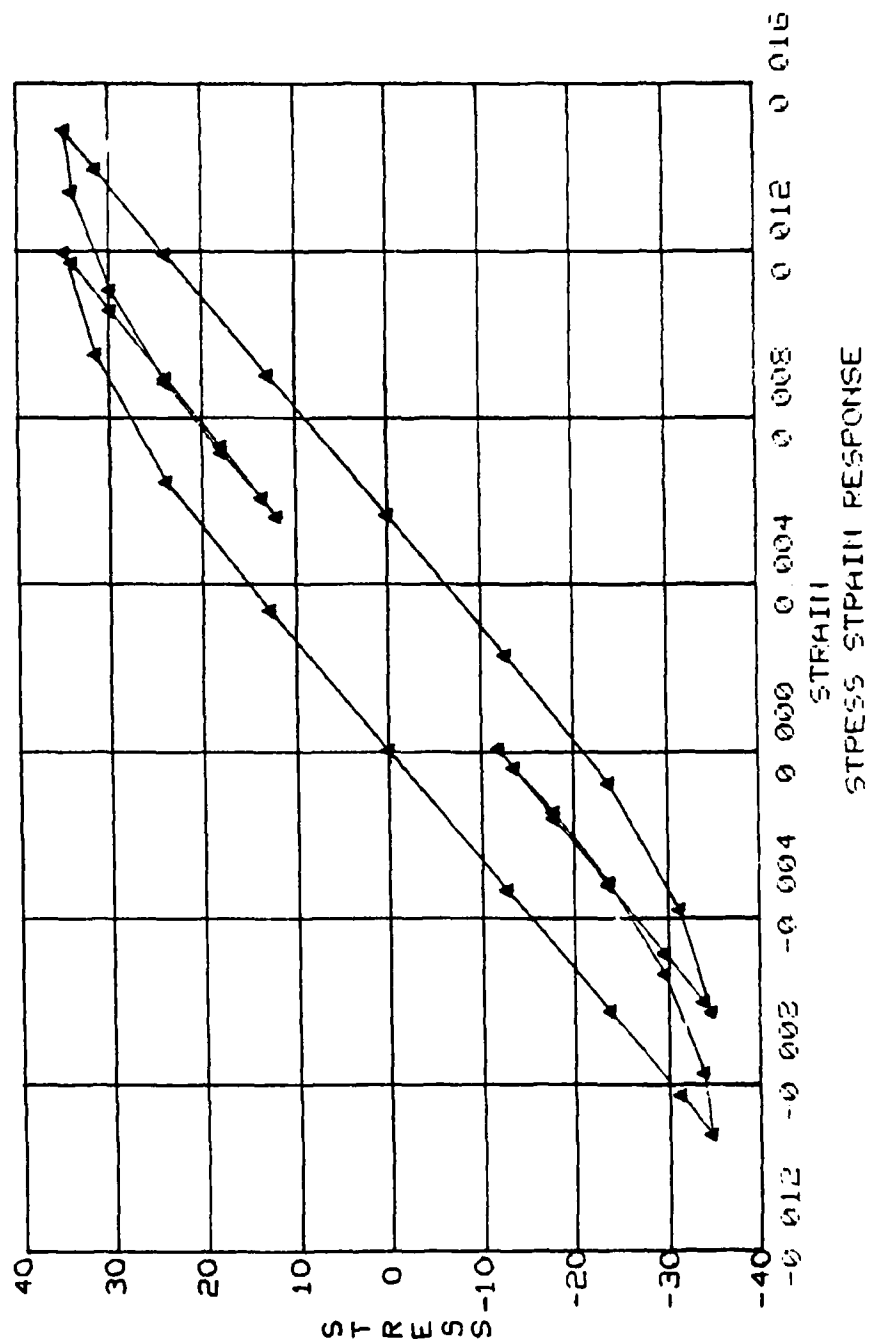
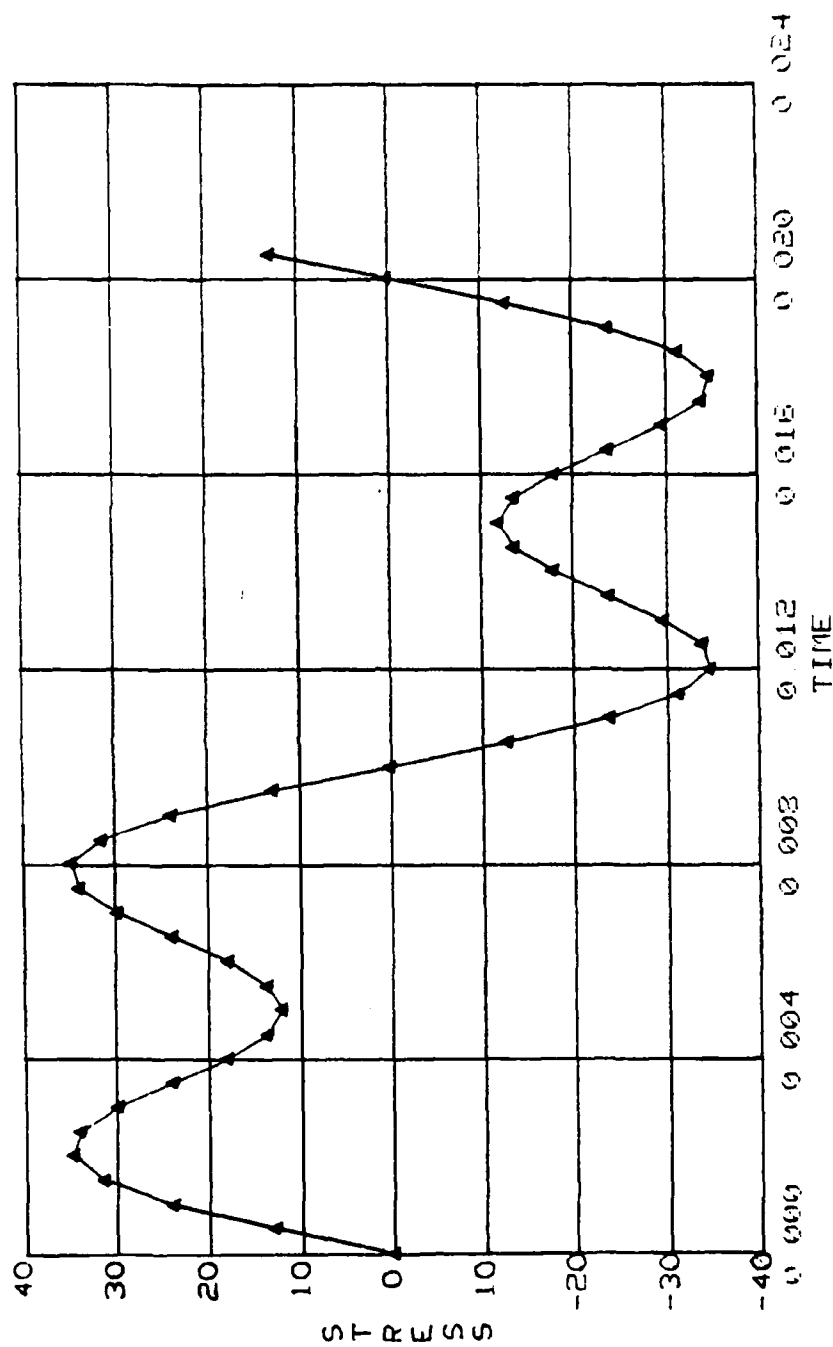


FIGURE 11



STRESS TIME HISTORY

FIGURE 12

was obtained using both terms. This two step procedure greatly reduced the incidence of non convergence, but, even using double precision, did not entirely eliminate these difficulties if the stress levels were too high.

A second problem was encountered due to the relaxation phase of the loading. Since b and d are not integers, a negative strain rate raised to such a power has no meaning. Furthermore, it can be assumed from standard hysteresis loop response that relaxation is essentially an elastic phenomenon. For these reasons, only the first term of the equation, with appropriate absolute values, is used during relaxation.

The final problem arose from the plastic deformation which may occur. Since equation (5) presumes a zero strain at zero stress, an appropriate plastic strain offset must be added to the solution after any relaxation. This plastic effect is clearly shown in Figure 9.

Using the solutions generated by equation (5) it is now possible to follow the strain and strain rate response of the system and to directly use equation (1) to predict ultimate stress. This procedure enables one to realistically use available ultimate stress values as a fracture criterion.

The point may be made that yield rather than ultimate stress would be a more conservative, and more meaningful injury criterion. Yield stress would unquestionably be more conservative, though some questions must first be answered. First, of course, yield point must be defined. This definition is arbitrary, depending on the material. For most engineering metals, yield is defined in terms of that stress which produces a plastic strain of .002. There is no such accepted standard for bone and all figures reported in the literature are for ultimate strengths. If a yield point definition could be agreed upon for bone, then yield strengths could be defined from the solution of equation (5).

A perhaps more interesting question is, what is the biological effect in living bone of exceeding the "yield strength?" No known investigation has been made into this phenomenon and its relation to injury. In fact, the overall level of understanding of bone fracture mechanics is quite low. For example, it is conceivable that reconstruction in living bone would overcome yielding effects without injury.

IV. CONCLUSIONS AND RECOMMENDATIONS

Given the available bone fracture data and the constraints of the current ATB model, a reasonable mechanism has been developed for utilizing a long bone fracture injury criterion for the ATB model. Specifically, this mechanism is based on a mathematical representation of the behavior of bone using the Ramberg-Osgood equation and on an approximation of the stress-time history of the bone generated using the ATB joint and contact forces. The specific injury criterion which should be employed is still under consideration. Options include: ultimate strength, which would be non conservative but for which considerable data exist; yield strength, which would be conservative, but for which a definition, and hence data, do not exist; some fraction of either of these as a factor of safety; or some other criterion such as maximum strain or strain energy. At present the ultimate strength, reduced by a factor of safety, is thought to be the best criterion. (The pulse criterion discussed in the first report (1) is felt to have value only as a comparison to existing automobile standards and hence to have no applicability to the pilot ejection problem.) The resulting injury criterion program remains in the "post processor" mode, i.e. it is not integrated into the ATB model, and this is the preferred configuration until the methodology becomes more fixed.

The Ramberg-Osgood equation appears to provide a very good means of mathematically modelling the stress-strain-strain rate behavior of bone. The fact that this equation, through proper optimization techniques, can be used to represent the three very different responses of bone shown here from the literature leads one to suspect that, whatever the "true" response of bone may be, it can be adequately described by equation (3). This flexibility, coupled with the dearth of good data on dynamic bone properties, was a prime motivating factor in taking this approach.

Further areas of inquiry point strongly in the direction of establishing a more comprehensive and consistent data base. The state-of-the-art in modeling has clearly outstripped both the available information on bone material properties and whole bone geometry, and the understanding of the mechanisms of bone fracture. A thorough understanding of these properties and mechanisms is necessary before any strides can be made toward formulating a more effective long bone injury criterion. The present criterion is designed to adapt to new information as it becomes available through modification of the constants in the Ramberg-Osgood equation and represents, in its present form, the most sophisticated injury criterion available.

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(While no support for this graduate student was received from this grant, he did contribute much of the work reported here while working toward his M.S. degree. A thesis is currently in preparation in absentia with an expected completion date of May 1982).

PUBLICATIONS:

in preparation, "Mathematical modeling of the stress-strain-strain rate behavior of bone using the Ramberg-Osgood equation," T.K. Hight, J.F. Brandeau (probable journal - J. Biomech.).

in preparation, "Development of a strain rate dependent injury criterion for long bones," T.K. Hight, J.F. Brandeau (probable journal - J. Biomech.).

INTERACTIONS:

Seminar presented at WPAFB/AFAMRL August 7, 1981 "Improved long bone injury criteria for use with the ATB model."

APPENDIX

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*****00000010
PROGRAM NAME : MYFIT                                *00000020
WRITTEN BY : J.F. BRANDEAU                          *00000030
COMPILER(S) : WATFIV (DOUBLE PRECISION)             *00000040
                                                    *00000050
-----*00000060
PURPOSE : FIT A FUNCTION OF N VARIABLES TO A SET OF M OBSERVED DATA *00000070
POINTS BY MINIMIZING THE DIFFERENCES BETWEEN OBSERVED AND PREDICTED *00000080
VALUES. THIS IS DONE USING SUBROUTINE FMIN (A COMBINATION OF GOLDEN *00000090
SEARCH & PARABOLIC INTERPOLATION METHODS) IN EACH OF THE COORDINATE *00000100
DIRECTIONS (X). THIS PROCEDURE STOPS WHEN ONE OR MORE TERMINATION *00000110
CRITERIA ARE MET : *00000120
1) ALL STEPS THROUGH TWO CONSECUTIVE SERIES ARE ABSOLUTELY LESS *00000130
   THAN TOL. *00000140
2) FRACTIONAL CHANGE OF FUNCTION VALUE IS ABSOLUTELY LESS THAN *00000150
   TOL THROUGH ONE SERIES. *00000160
3) MAXIMUM # OF SERIES IS EXCEEDED. *00000170
-----*00000180
PROGRAM VARIABLES : SUGGESTED VALUES TO START WITH IN {} *00000190
                                                    *00000200
NSCALE : CONTROLS LENGTH OF INTERVAL SENT TO FMIN. THE VALUE OF X(I) *00000210
IS MULTIPLIED BY (1+NSCALE(I)) AND (1-NSCALE(I)). IF THE INTERVAL *00000220
INCLUDES ZERO, THIS ALLOWS FOR MAJOR CHANGES OF VARIABLE X(I) IN THE *00000230
ABSOLUTELY SMALLER DIRECTION. NOTE -- IF NSCALE(I) IS 0.0, THE *00000240
VALUE OF X(I) DOES NOT CHANGE IN THE PROGRAM. IN THIS WAY THE VAR- *00000250
IABLE X(I) CAN BE FIXED. (1.0 FOR ALL). *00000260
                                                    *00000270
TOL : CONVERGENCE LIMIT FOR ALL CRITERIA (1.0D-7). *00000280
                                                    *00000290
MAXFN : MAXIMUM # OF FUNCTION EVALUATIONS ALLOWED (25). *00000300
                                                    *00000310
TIMES : MULTIPLIER FOR EACH ABSOLUTE ERROR (VALUE WHICH WILL MAKE THE *00000320
ERROR GREATER THAN 1.0). *00000330
                                                    *00000340
UP : POWER WHICH (TIMES * ABS. ERROR) IS RAISED TO (2.0). *00000350
-----*00000360
PENALTY CONTROLS : PENALIZES FUNCTION IF ABS ERROR AT ANY POINT IS *00000370
GREATER THAN A SPECIFIED AMOUNT. *00000380
                                                    *00000390
ERROR : ALLOWABLE ERROR WITHOUT PENALTY (1.5D-3). *00000400
                                                    *00000410
Z : POWER WHICH (ABS. ERROR * TIMES) IS RAISED TO. THIS IS THE *00000420
PENALTY STEP FUNCTION (IF ABS. ERROR GT. ERROR ; PENALTY = ABS. *00000430
ERROR * TIMES ) ** Z, -- ELSE PENALTY = 0) THIS IS A RUNNING SUM. *00000440
(Z IS USUALLY 2.0). *00000450
-----*00000460
OTHERS VARIABLES : *00000470
                                                    *00000480
X & COEFF : MANTISSA & EXPONENT OF VARIABLES. AFTER EACH SERIES X IS *00000490
NORMALIZED TO BETWEEN 1.0 & 10.0 TO ALLOW LARGE DELTA X'S AND AID *00000500

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: CONVERGENCE CRITERIA ACCURACY. THE PRODUCT X(I) * COEFF(I) IS THE *00000510
: VALUE OF THE VARIABLE COEFFICIENT. *00000520
: *00000530
: STRESS : OBSERVED VALUES OF STRESS (KSI). *00000540
: *00000550
: RATE : OBSERVED VALUES OF STRAIN RATE (1/SEC). *00000560
: *00000570
: Y : OBSERVED VALUES OF STRAIN (IN/IN). *00000580
: *00000590
: YAPROX : PREDICTED VALUES OF STRAIN (IN/IN). *00000600
: ----- *00000610
: CCOMP OPTIONS : FORM C$OPTIONS CCOMP=????? *00000620
: *00000630
: 3 : OUTPUTS FUNCTION AND POINT OF EVALUATION FOR EACH EVALUATION. *00000640
: 4 : OUTPUT VALUE OF X & FMIN INTERVAL (AX & BX), PENALTIES AND *00000650
: FUNCTION VALUES FOR EACH COORDINATE DIRECTION. *00000660
: 5 : ALLOWS READING FROM INPUT LIST AT END OF PROGRAM FOR X & COEFF. *00000670
: PROGRAM ALWAYS READS THESE FROM FILE #5 REGARDLESS. FILE #1 *00000680
: VALUES WILL OVERRIDE THESE. *00000690
: 6 : OUTPUTS PENALTY SUMMATION AT TERMINATION. *00000700
: 7 : OUTPUTS LIST OF OBSERVED AND PREDICTED VALUES AT TERMINATION. *00000710
: ----- *00000720
: I/O REQUIREMENTS : *00000730
: *00000740
: FILE #1 : CONTAINS INPUT VARIABLES AS DESCRIBED ABOVE FOLLOWING $DATA *00000750
: CARD AT END OF PROGRAM. *00000760
: FILE #4 : CONTAINS OBSERVED VALUES. THE FIRST RECORD MUST BE A TITLE *00000770
: FILE #5 : CONTAINS X & COEFF ON TWO RECORDS. UPDATED AT TERMINATION. *00000780
: *00000790
: *****00000800
: $OPTIONS CCOMP=0 00000810
: ON ERROR GO TO 70 00000820
: IMPLICIT REAL * 8 (A-H, O-Z) 00000830
: REAL NSCALE(5) 00000840
: DIMENSION X(5), STRESS(60), Y(60), RATE(60), YAPROX(60) 00000850
: DIMENSION A(5), DIFF(60) 00000860
: INTEGER TITLE(20) 00000870
: COMMON STRESS, Y, RATE, YAPROX, M, SSQ, DIFF, TIMES 00000880
: COMMON /WEIGHT/ R, Z, ERROR, Numpen, PENAL 00000890
: COMMON /SEARCH/ EPS 00000900
: COMMON /FUN1/ COEFF(5), TOTAL, UP, A, I 00000910
: EXTERNAL FUNCT 00000920
: DATA NSCALE /0.90, 0.90, 1.00, 1.00, 1.00 / 00000930
: 00000940
: SET PROGRAM PARAMETERS 00000950
: 00000960
: Z = 2.0D0 ; UP = 2.0D0 ; R = 10.0D0 00000970
: TOL = 1.0D-7 ; ERROR = 1.0D-4 ; MAXFN = 20 00000980
: TIMES = 1.0D3 00000990
: 00001000

```


C		00001010
C	CALCULATE SQUARE ROOT OF MACHINE EPSILON FOR SUBROUTINE FMIN	00001020
C		00001030
	EPS = 1.0D00	00001040
10	EPS = EPS / 2.0D0	00001050
	TOL1 = 1.0D0 + EPS	00001060
	IF (TOL1 .GT. 1.0D00) GO TO 10	00001070
	EPS = DSQRT(EPS)	00001080
	KOUNT = NUNPEN = 0	00001090
	READ (1,*) N	00001100
	READ (5,*) (X(I), I = 1, N)	00001110
	READ (5,*) (COEFF(I), I = 1, N)	00001120
C5	READ (1,*) (X(I), I = 1, N)	00001130
C5	READ (1,*) (COEFF(I), I = 1, N)	00001140
	READ (4,95) TITLE	00001150
	M = 1	00001160
20	READ (4,*,END=25) RATE(M), Y(M), STRESS(M)	00001170
	M = M + 1	00001180
	GO TO 20	00001190
25	M = M - 1	00001200
	I = 1 : POINT = X(I)	00001210
	WRITE (3,98) TITLE	00001220
	WRITE (3,105) TOL, UP, R, Z, ERROR	00001230
	WRITE (3,106) TIMES	00001240
	WRITE (3,108) (NSCALE(J), J = 1, N)	00001250
	WRITE (3,107) M	00001260
	DO 30 J = 1, N	00001270
	WRITE (3,110) J, X(J), COEFF(J)	00001280
30	A(J) = X(J) * COEFF(J)	00001290
	HOLD = FUNCT (POINT)	00001300
	WRITE (3,100) HOLD	00001310
	IF (NUNPEN .GT. 0) WRITE (3,125) NUNPEN, PENAL	00001320
	DO 60 K = 1, MAXPN	00001330
	IOUT = KOUNT2 = 0	00001340
	DO 50 I = 1, N	00001350
	DO 40 J = 1, N	00001360
40	A(J) = X(J) * COEFF(J)	00001370
C4	WRITE (3,110) I, X(I), COEFF(I)	00001380
	IF (X(I) .EQ. 0.0D0 .OR. NSCALE(I) .EQ. 0.0) THEN DO	00001390
	G = X(I)	00001400
	KOUNT2 = KOUNT2 + 1	00001410
	GO TO 50	00001420
	ENDIF	00001430
	IF (X(I) .GT. 0.0D0) THEN DO	00001440
	GLOW = X(I) * (1.0 - NSCALE(I))	00001450
	GHIGH = X(I) * (1.0 + NSCALE(I))	00001460
	IF (GLOW .LT. 1.0D-3 .AND. GLOW .GT. 0.0D0) GLOW = -GLOW	00001470
	ELSE DO	00001480
	GLOW = X(I) * (1.0 + NSCALE(I))	00001490
	GHIGH = X(I) * (1.0 - NSCALE(I))	00001500

	IF (GHIGH .GT. -1.0D-3 .AND. GHIGH .LT. 0.0D0) GHIGH = -GHIGH	00001510
	ENDIF	00001520
C4	WRITE (3,115) GLOW, GHIGH	00001530
	G = FMIN (GLOW, GHIGH, FUNCT, TOL)	00001540
	TOTAL = FUNCT (G)	00001550
C4	WRITE (3,120) G, SSQ	00001560
C4	IF (Numpen .GT. 0) WRITE (3,125) Numpen, PENAL	00001570
C4	IF (TOTAL .GT. HOLD) THEN DO	00001580
C4	PRINT, 'BAD STEP?'	00001590
C4	ENDIF	00001600
C4	WRITE (3,160) TOTAL	00001610
45	IF (DABS(X(I)-G) .GT. TOL) IOUT = 1	00001620
	IF (DABS((TOTAL-HOLD)/HOLD) .LT. TOL) KOUNT2 = KOUNT2 + 1	00001630
	HOLD = TOTAL	00001640
50	X(I) = G	00001650
C		00001660
C	NORMALIZE X'S TO BETWEEN 1.0 & 10.0. CORRECT CHANGE IN VALUE OF	00001670
C	COEFF SO PRODUCT IS SAME.	00001680
C		00001690
	DO 55 I = 1, N	00001700
	IF (X(I) .EQ. 0.0D0) GO TO 55	00001710
	WHILE (DABS(X(I)) .LT. 1.0D0) DO	00001720
	X(I) = X(I) * 10.0D0	00001730
	COEFF(I) = COEFF(I) / 10.0D0	00001740
	END WHILE	00001750
55	CONTINUE	00001760
C		00001770
C	CHECK AND UPDATE CONVERGENCE CRITERIA - TERMINATE IF MET	00001780
C		00001790
	IF (IOUT .EQ. 0) KOUNT = KOUNT + 1	00001800
	IF (KOUNT .EQ. 2) THEN DO	00001810
	WRITE (3,135) TOL	00001820
	WRITE (3,145) K	00001830
	GO TO 70	00001840
	ENDIF	00001850
	IF (KOUNT2 .EQ. N) THEN DO	00001860
	WRITE (3,140) TOL	00001870
	WRITE (3,145) K	00001880
	GO TO 70	00001890
	ENDIF	00001900
C		00001910
60	CONTINUE	00001920
	WRITE (3,147) MAXFN	00001930
70	DO 80 J = 1, N	00001940
80	WRITE (3,110) J, X(J), COEFF(J)	00001950
	REWIND 5	00001960
	WRITE (5,130) (X(I), I = 1, N)	00001970
	WRITE (5,130) (COEFF(I), I = 1, N)	00001980
	WRITE (3,150) TOTAL	00001990
	IF (Numpen .GT. 0) WRITE (3,155) Numpen	00002000

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:6      B3 = PENLTY (1)                                00002010
:7      WRITE (3,165)                                  00002020
:7      DO 85 I = 1, M                                00002030
:7      WRITE (3,170) I, STRESS(I), RATE(I), Y(I), YAPROX(I) 00002040
:7 85 CONTINUE                                         00002050
      STOP                                             00002060
      95 FORMAT (20A4)                                00002070
      98 FORMAT (1H1,'TITLE : ',20A4/)                00002080
      100 FORMAT (1H , ' AT START, FUNCT =', 1PD21.13//) 00002090
      105 FORMAT (1H-,'PROGRAM PARAMETERS:',/,T24,' TOL =',1PD9.2,/,T4, 00002100
      * 'ABS ERROR RAISED TO POWER:',1PD9.2,/,/, ' PENALTY CONTROLS:',/,T15, 00002110
      * 'MULTIPLIER =',1PD12.5,/,T20,'POWER =',1PD9.2,/,T14, 00002120
      * 'ERROR LEVEL =',1PD12.5//)                    00002130
      106 FORMAT (1H , 'TIMES =',1PD10.3)              00002140
      107 FORMAT (1H ,I3,' POINTS WERE OBSERVED'//)    00002150
      108 FORMAT (' SCALE VECTOR IS: ',6F6.2/)         00002160
      110 FORMAT (' ----- X(' ,I2,' ) =',1PD21.13,' * ',1PD8.1) 00002170
      115 FORMAT (' SEARCH RANGE ',1PD12.5,' TC ',1PD12.5) 00002180
      120 FORMAT (1H , 'MINIMUM POINT @ G = ',1PD21.13,/,T15, 00002190
      * 'SSQ =',1PD21.13)                             00002200
      125 FORMAT (I4,' CONSTRAINTS VIOLATED -- PENALTY =',1PD13.5) 00002210
      130 FORMAT (5D21.13)                             00002220
      135 FORMAT (' CONVERGENCE OF ALL X'S TO WITHIN',1PD12.3) 00002230
      140 FORMAT (' DELTA FUNCT HAS BEEN LESS THAN',1PD12.5,' FOR 5 STEPS') 00002240
      145 FORMAT (1H-,'FINAL RESULT REACHED AFTER ',I3,' SERIES') 00002250
      147 FORMAT (1H-,'NO CONVERGENCE AFTER ',I3,' SERIES') 00002260
      150 FORMAT (1H-,'AT FINISH, FUNCT =',1PD21.13)   00002270
      155 FORMAT ('OAT FINISH, ',I3,' CONSTRAINTS VIOLATED:',/, 00002280
      * 1H ,T6,'#',T10,'STRESS(KSI) ',T28,'RATE', 00002290
      * T38,'PRED. STRAIN',T52,'OBS. STRAIN',T69,'DIFF'//) 00002300
      160 FORMAT ('-FUNCT =',1PD21.13/)                00002310
      165 FORMAT (1H0,/,T4,'#',T15,'STRESS(KSI) ',T34,'RATE',T45,'OBS. STRAIN' 00002320
      * ,T60,'PRED. STRAIN'//)                         00002330
      170 FORMAT (1H ,T3,I2,T10,4(1PD15.3))           00002340
      END                                              00002350
      DOUBLE PRECISION FUNCTION FUNCT(POINT)           00002360
      IMPLICIT REAL * 8 (A-H, O-Z)                    00002370
      DIMENSION X(5),STRESS(60),Y(60),RATE(60),YAPROX(60),DIFF(60) 00002380
      COMMON STRESS, Y, RATE, YAPROX, M, SSQ, DIFF, TIMES 00002390
      COMMON /FUN1/ COEFF(5), TOTAL, UP, X, II         00002400
      SSQ = 0.0D0                                       00002410
      X(II) = POINT * COEFF(II)                        00002420
      00002430
      CALCULATE PREDICTED STRAINS AND SUM OF ERRORS.  00002440
      00002450
      DO 10 I = 1, M                                   00002460
      IF (STRESS(I) .EQ. 0.0D0) THEN DO                00002470
      YAPROX(I) = DIFF(I) = 0.0DC                     00002480
      GO TO 10                                          00002490
      ENDIF                                           00002500

```

TEMP2 = STRESS(I) / X(5) / RATE(I) ** X(4)	00002510
TEMP3 = RATE(I) ** X(2) * STRESS(I) ** X(3)	00002520
YAPROX(I) = TEMP2 + X(1) * TEMP3	00002530
APPLY WEIGHTING FACTORS TO RESIDUAL	00002540
DIF = DABS(YAPROX(I) - Y(I))	00002550
SSQ = SSQ + (DIF * TIMES) ** UP	00002560
DIFF(I) = DIF	00002570
10 CONTINUE	00002580
TOTAL = SSQ + PENLTY (0)	00002590
FUNCT = TOTAL	00002600
33 WRITE (3,100) POINT, FUNCT	00002610
RETURN	00002620
100 FORMAT (1H , 'AT FUNCT, POINT =', 1PD21.13, ' FUNCT =', 1PD21.13)	00002630
END	00002640
DOUBLE PRECISION FUNCTION PENLTY (IDUM)	00002650
IMPLICIT REAL * 8 (A-H, O-Z)	00002660
DIMENSION STRESS(60), Y(60), RATE(60), YAPROX(60), DIFF(60)	00002670
COMMON STRESS, Y, RATE, YAPROX, M, SSQ, DIFF, TIMES	00002680
COMMON /WEIGHT/ R, Z, ERROR, KOUNT, HOLD	00002690
HOLD = 0.0D0	00002700
KOUNT = 0	00002710
CALCULATE PENALTY IF ABS. ERROR GREATER THAN SPECIFIED MAX.	00002720
DO 10 I = 1, M	00002730
B3 = DIFF(I)	00002740
IF (B3 .GT. ERROR) THEN DO	00002750
HOLD = HOLD + (B3 * TIMES) ** 2	00002760
KOUNT = KOUNT + 1	00002770
IF (IDUM .EQ. 1) THEN DO	00002780
WRITE (3,100) KOUNT, STRESS(I), RATE(I), YAPROX(I), Y(I), B3	00002790
ENDIF	00002800
ENDIF	00002810
10 CONTINUE	00002820
PENLTY = HOLD = HOLD * R	00002830
100 FORMAT (1H , I5, 5(1PD14.5))	00002840
RETURN ; END	00002850
ISOPTIONS NOLIST	00002860
DOUBLE PRECISION FUNCTION PHIN(AX, BX, P, TOL)	00002870
DOUBLE PRECISION AX, BX, P, TOL	00002880
DOUBLE PRECISION A, B, C, D, E, EPS, XM, P, Q, R, TOL1, TOL2, U, V, W	00002890
DOUBLE PRECISION PU, PV, FW, FX, X	00002900
DOUBLE PRECISION DABS, DSQRT, DSIGN	00002910
COMMON /SEARCH/ EPS	00002920
C = 0.5D0*(3. - DSQRT(5.0D0))	00002930
A = AX	00002940
B = BX	00002950
	00002960
	00002970
	00002980
	00002990
	00003000

V = A + C*(B - A)	00003010
W = V	00003020
X = V	00003030
E = 0.0D0	00003040
FX = F(X)	00003050
FV = FX	00003060
FW = FX	00003070
20 XM = 0.5D0*(A + B)	00003080
TOL1 = EPS*DABS(X) + TOL/3.0D0	00003090
TOL2 = 2.0D0*TOL1	00003100
IF (DABS(X - XM) .LE. (TOL2 - 0.5D0*(B - A))) GO TO 90	00003110
IF (DABS(E) .LE. TOL1) GO TO 40	00003120
R = (X - W)*(FX - FV)	00003130
Q = (X - V)*(FX - FW)	00003140
P = (X - V)*Q - (X - W)*R	00003150
Q = 2.0D00*(Q - R)	00003160
IF (Q .GT. 0.0D0) P = -P	00003170
Q = DABS(Q)	00003180
R = E	00003190
E = D	00003200
30 IF (DABS(P) .GE. DABS(0.5D0*Q*R)) GO TO 40	00003210
IF (P .LE. Q*(A - X)) GO TO 40	00003220
IF (P .GE. Q*(B - X)) GO TO 40	00003230
D = P/Q	00003240
U = X + D	00003250
IF ((U - A) .LT. TOL2) D = DSIGN(TOL1, XM - X)	00003260
IF ((B - U) .LT. TOL2) D = DSIGN(TOL1, XM - X)	00003270
GO TO 50	00003280
40 IF (X .GE. XM) E = A - X	00003290
IF (X .LT. XM) E = B - X	00003300
D = C*E	00003310
50 IF (DABS(D) .GE. TOL1) U = X + D	00003320
IF (DABS(D) .LT. TOL1) U = X + DSIGN(TOL1, D)	00003330
FU = F(U)	00003340
IF (FU .GT. FX) GO TO 60	00003350
IF (U .GE. X) A = X	00003360
IF (U .LT. X) B = X	00003370
V = W	00003380
FV = FW	00003390
W = X	00003400
FW = FX	00003410
X = U	00003420
FX = FU	00003430
GO TO 20	00003440
60 IF (U .LT. X) A = U	00003450
IF (U .GE. X) B = U	00003460
IF (FU .LE. FW) GO TO 70	00003470
IF (W .EQ. X) GO TO 70	00003480
IF (FU .LE. FV) GO TO 80	00003490
IF (V .EQ. X) GO TO 80	00003500

```

      IF (V .EQ. W) GO TO 80
      GO TO 20
70    V = W
      FV = FW
      W = U
      FW = FU
      GO TO 20
80    V = U
      FV = FU
      GO TO 20
90    FMIN = X
      RETURN
      END

```

DATA

5

3.85D0	-2.35D0	4.52D0	2.106D0	1.694D0
1.0D-68	1.0D0	1.0D1	1.0D-2	1.0D3

```

00003510
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```

*****00000010
C      *00000020
C PROGRAM NAME : SOLVALL *00000030
C WRITTEN BY : J.F. BRANDEAU *00000040
C COMPILER(S) : WATFIV (DOUBLE PRECISION) *00000050
C ----- *00000060
C PURPOSE : TO CONVERT EQUATION STRAIN = F(RATE, STRESS) TO EQUATION *00000070
C STRESS = F(RATE, STRAIN) USING SUBROUTINE ZEROIN TO SOLVE FOR ROOT OF *00000080
C THE EQUATION. CAN HANDLE UP TO SIX SETS OF COEFFICIENTS X TO PRODUCE *00000090
C UP TO SIX DATA PAIRS FOR SAS TO GRAPH ON A SINGLE GRAPH. *00000100
C ----- *00000110
C VARIABLES : *00000120
C *00000130
C KGRAPS : NUMBER OF SETS OF COEFFICIENTS TO BE TAKEN FROM DATA. *00000140
C *00000150
C RATE : STRAIN RATE TO BE USED. *00000160
C *00000170
C KEPS : NUMBER OF POINTS TO BE GENERATED FOR EACH UNIQUE VECTOR X. *00000180
C *00000190
C TOL : CONVERGENCE CRITERION FOR ZEROIN. *00000200
C *00000210
C A, B, N, D, C (I) - SET OF COEFFICIENTS FOR EACH CURVE. THE I'TH *00000220
C ELEMENT OF EACH CONSTITUTES ONE SET OF COEFFICIENTS X. *00000230
C *00000240
C SIGMAX : MAXIMUM VALUE OF STRESS (KSI) EXPECTED FOR EACH SET OF *00000250
C COEFFICIENTS X. THIS IS THE HIGH LIMIT SENT TO ZEROIN. THESE MAY *00000260
C BE ADJUSTED DOWNWARD BY THE PROGRAM IF NEEDED TO PREVENT UNDER/OVER *00000270
C FLOWS. IF THE VALUE OF SIGMAX(I) IS NOT HIGH ENOUGH FOR COEFFICIENT *00000280
C X(I), THE CURVE WILL BE FLATTENED AT THE HIGHER STRESSES. *00000290
C *00000300
C EPSMAX : MAXIMUM VALUE OF STRAIN FOR WHICH EACH CURVE IS TO BE *00000310
C EVALUATED. *00000320
C ----- *00000330
C I/O REQUIREMENTS : *00000340
C *00000350
C FILE #1 : ALL INPUT FROM ABOVE, FOLLOWING $DATA CARD. *00000360
C FILE #6 : OUTPUT OF STRESS-STRAIN PAIRS FOR USE BY SAS (LRECL=130). *00000370
C ----- *00000380
C *00000390
C CCOMP OPTIONS (FORM C$OPTIONS CCOMP=?????) : *00000400
C *00000410
C 4 : OUTPUT OF RETURNED STRESS VALUES. *00000420
C *00000430
*****00000440
C$OPTIONS CCOMP=0 00000450
C IMPLICIT REAL * 8 (A-H, N, O-Z) 00000460
C EXTERNAL PUNCT 00000470
C DIMENSION A(6), B(6), C(6), D(6), N(6), SIGMAX(6), EPSMAX(6) 00000480
C DIMENSION EPS(50,6), STRESS(50,6) 00000490
C COMMON A, B, C, D, N, TLOG, RATE, KOUNT, J, EPS, RATEB, RATED 00000500

```

COMMON /SUB2/ GEPS	00000510
CALCULATE MACHINE EPSILON	00000520
GEPS = 1.0D0	00000530
4 GEPS = GEPS/2.0D0	00000540
TOL1 = 1.0D0 + GEPS	00000550
IF (TOL1 .GT. 1.0D0) GO TO 4	00000560
READ (1,*) KGRAFS, RATE, KEPS, TOL	00000570
TEPS = 0.0D0	00000580
DO 10 I = 1, KGRAFS	00000590
READ (1,*) A(I), B(I), N(I), D(I), C(I), SIGMAX(I), EPSMAX(I)	00000600
CHECK FOR POSSIBLE OVERFLOW FOR HIGH N'S	00000610
ALTER SIGMAX DOWNWARD IF NECESSARY	00000620
RATEB = DLOG10 (RATE ** B(I))	00000630
6 AX = N(I) * DLOG10 (SIGMAX(I)) + RATEB	00000640
IF (AX .GT. 75.0D0) THEN DO	00000650
SIGMAX(I) = SIGMAX(I) - 0.5D0	00000660
GO TO 6	00000670
ENDIF	00000680
10 CONTINUE	00000690
BEGIN MAIN LOOP	00000700
DO 30 KOUNT = 1, KGRAFS	00000710
STRESS(1,KOUNT) = EPS(1,KOUNT) = 0.0D0	00000720
BX = SIGMAX(KOUNT)	00000730
DEPS = EPSMAX(KOUNT) / DFLOAT(KEPS-1)	00000740
RATED = RATE ** D(KOUNT)	00000750
RATEB = RATE ** B(KOUNT)	00000760
WATCHING FOR VALUES OF N THAT WILL CAUSE OVERFLOW OR UNDERFLOW	00000770
IF (A(KOUNT) .EQ. 0.0D0) THEN DO	00000780
TLOG = -80.0D0	00000790
ELSE DO	00000800
TLOG = DLOG10 (A(KOUNT))	00000810
ENDIF	00000820
INNER LOOP FOR EACH SOLUTION	00000830
DO 20 J = 2, KEPS	00000840
EPS(J,KOUNT) = DFLOAT(J-1) * DEPS	00000850
AX = STRESS(J-1,KOUNT)	00000860
IF (J .EQ. 2) AX = (C(KOUNT) * EPS(J,KOUNT) * RATED) / 1.3D0	00000870
STRESS(J,KOUNT) = ZEROIN (AX, BX, FUNCT, TOL)	00000880
PRINT, 'FROM ZEROIN, STRESS', J, ' = ', STRESS(J,KOUNT)	00000890
	00000900
	00000910
	00000920
	00000930
	00000940
	00000950
	00000960
	00000970
	00000980
	00000990
	00001000

20	CONTINUE	00001010
30	CONTINUE	00001020
	DO 40 I = 1, KEPS	00001030
40	WRITE (6,100) (EPS(I,J), STRESS(I,J), J = 1, KGRAPS)	00001040
50	STOP	00001050
100	FORMAT (10(1PD13.5))	00001060
	END	00001070
	DOUBLE PRECISION FUNCTION FUNCT(STRESS)	00001080
	IMPLICIT REAL * 8 (A-H, N, O-Z)	00001090
	DIMENSION A(6), B(6), C(6), D(6), N(6), EPS(50,6)	00001100
	COMMON A, B, C, D, N, TLOG, RATE, KOUNT, J, EPS, RATEB, RATED	00001110
	IF (STRESS.EQ. 0.0D0) THEN DO	00001120
	FUNCT = -EPS(J,KOUNT)	00001130
	RETURN	00001140
	ENDIF	00001150
	TEMP1 = STRESS / (C(KOUNT) * RATED)	00001160
	IF (STRESS.GT. 1.0D-1) GO TO 10	00001170
	IF ((N(KOUNT) * DLOG10(STRESS)) .LT. -60.0D0) THEN DO	00001180
	HOLD = -25.0D0	00001190
	GO TO 15	00001200
	ENDIF	00001210
10	TEMP2 = STRESS ** N(KOUNT) * RATEB	00001220
	HOLD = DLOG10(TEMP2)	00001230
15	IF ((HOLD + TLOG) .LT. -17.0D0) THEN DO	00001240
	FUNCT = TEMP1 - EPS(J,KOUNT)	00001250
	ELSE DO	00001260
	FUNCT = (TEMP1 + A(KOUNT) * TEMP2) - EPS(J,KOUNT)	00001270
	ENDIF	00001280
25	RETURN : END	00001290
30	OPTIONS NOLIST	00001300
	DOUBLE PRECISION FUNCTION ZEROIN(AX,BX,F,TOL)	00001310
	DOUBLE PRECISION AX,BX,F,TCL	00001320
	DOUBLE PRECISION A,B,C,D,E,EPS,FA,FB,FC,TOL1,XM,P,Q,R,S	00001330
	DOUBLE PRECISION DABS,DSIGN	00001340
	COMMON /SUB2/ EPS	00001350
	A = AX	00001360
	B = BX	00001370
	FA = F(A)	00001380
	FB = F(B)	00001390
20	C = A	00001400
	FC = FA	00001410
	D = B - A	00001420
	E = D	00001430
30	IF (DABS(FC) .GE. DABS(FB)) GO TO 40	00001440
	A = B	00001450
	B = C	00001460
	C = A	00001470
	FA = FB	00001480
	FB = FC	00001490
	FC = FA	00001500

40	TOL1 = 2.0D0*EPS*DABS(B) + 0.5D0*TOL	00001510
	XM = .5*(C - B)	00001520
	IF (DABS(XM) .LE. TOL1) GO TO 90	00001530
	IF (FB .EQ. 0.0D0) GO TO 90	00001540
	IF (DABS(E) .LT. TOL1) GO TO 70	00001550
	IF (DABS(FA) .LE. DABS(FB)) GO TO 70	00001560
	IF (A .NE. C) GO TO 50	00001570
	S = FB/FA	00001580
	P = 2.0D0*XM*S	00001590
	Q = 1.0D0 - S	00001600
	GO TO 60	00001610
50	Q = FA/PC	00001620
	R = FB/PC	00001630
	S = FB/FA	00001640
	P = S*(2.0D0*XM*Q*(Q - R) - (B - A)*(R - 1.0D0))	00001650
	Q = (Q - 1.0D0)*(R - 1.0D0)*(S - 1.0D0)	00001660
60	IF (P .GT. 0.0D0) Q = -Q	00001670
	P = DABS(P)	00001680
	IF ((2.0D0*P) .GE. (3.0D0*XM*Q - DABS(TOL1*Q))) GO TO 70	00001690
	IF (P .GE. DABS(0.5D0*E*Q)) GO TO 70	00001700
	E = D	00001710
	D = P/Q	00001720
	GO TO 80	00001730
70	D = XM	00001740
	E = D	00001750
80	A = B	00001760
	FA = FB	00001770
	IF (DABS(D) .GT. TOL1) B = B + D	00001780
	IF (DABS(D) .LE. TOL1) B = B + DSIGN(TOL1, XM)	00001790
	FB = F(B)	00001800
	IF ((FB*(PC/DABS(PC))) .GT. 0.0D0) GO TO 20	00001810
	GO TO 30	00001820
90	ZEROIN = B	00001830
	RETURN	00001840
	END	00001850
SDATA		00001860
5	1.0D0 25 1.0D-7	00001870
5.1183D-13	-3.74D-1 6.5342D0 6.707D-2 3.5514D3 50.0D0 .016D0	00001880
36.777D-13	-4.1267D-1 7.6617D0 5.67034D-2 2.20498D3 25.0D0 .0060D0	00001890
3.052D-13	-1.426D-1 7.632D0 6.287D-2 2.284D3 20.0 .0070D0	00001900
3.709D-68	-2.3357D0 45.2472D0 1.7977D-2 1.694D3 45.0D0 .036D0	00001910
1.0D0 1.0D0 1.0D0	1.34946D-2 2.6354D2 15.0D0 .030D0	00001920

```

*****00000010
:                                     *00000020
: PROGRAM NAME : BAKSOLV                *00000030
: WRITTEN BY : J.F. BRANDEAU            *00000040
: COMPILER(S) : WATFIV (DOUBLE PRECISION) *00000050
:                                     *00000060
: -----
: PURPOSE : CONVERT EQUATION STRAIN = F(RATE, STRESS) TO EQUATION *00000070
: STRESS = F(RATE, STRAIN) BY USING SUBROUTINE ZEROIN TO SOLVE FOR ROOT *00000080
: OF EQUATION. PROGRAM CHECKS RATE TO DETERMINE EACH CHANGE AND *00000090
: PREVENT UNDER / OVER FLOW. 6 UNIQUE RATES ARE ALLOWED IN THE INPUT *00000100
: LIST FROM FILE #4.                  *00000110
: -----
: VARIABLES :                          *00000120
:                                     *00000130
:                                     *00000140
: SIGMAX : GREATER THAN MAXIMUM VALUE OF STRESS EXPECTED FOR EACH *00000150
: OBSERVED RATE. THIS IS THE UPPER LIMIT FOR ROOT SEARCH, AND IS *00000160
: ADJUSTED TO PREVENT OVER /UNDER FLOW. IF THIS IS TOO LOW THE CURVE *00000170
: FOR THAT STRAIN RATE WILL BE FLATTENED AT THE TOP. *00000180
:                                     *00000190
: TOL : CONVERGENCE CRITERION FOR ZEROIN. *00000200
:                                     *00000210
: X & COEFF : MANTISSA AND EXPONENT OF COEFFICIENT VECTOR. PROGRAM *00000220
: COMBINES BOTH INTO X. *00000230
: -----
: I / O REQUIREMENTS : *00000240
:                                     *00000250
:                                     *00000260
: FILE #4 : OBSERVED VALUES OF DATA AS USED FOR OTHER PROGRAMS. *00000270
: TITLE MUST BE ON FIRST RECORD, FOLLOWED BY ONE OBSERVATION *00000280
: PER RECORD; STRAIN RATE, STRAIN AND STRESS (IN ORDER). *00000290
: FILE #5 : X & COEFF. X IS THE MANTISSA AND COEFF THE EXPONENT OF *00000300
: THE VARIABLE COEFFICIENTS. PRODUCT X * COEFF SHOULD EQUAL *00000310
: THE COEFFICIENT. *00000320
: FILE #6 : OUTPUT OF POINTS FOR USE BY SAS. *00000330
:                                     *00000340
: *****00000350
: IMPLICIT REAL * 8 (A-H, O-Z)          00000360
: EXTERNAL FUNCT                          00000370
: DIMENSION X(5), SIGMAX(6), COEFF(5)    00000380
: COMMON X, RATE, EPS, RATEB, RATED      00000390
: INTEGER TITLE(20)                      00000400
: DATA SIGMAX / 50.0, 50.0, 50.0, 50.0, 50.0, 50.0/ 00000410
: TOL = 1.0D-7                           00000420
: READ (5,*) X                            00000430
: READ (5,*) COEFF                        00000440
: READ (4,200) TITLE                      00000450
: WRITE (3,300) TITLE                     00000460
: DO 5 J = 1, 5                           00000470
: X(J) = X(J) * COEFF(J)                  00000480
: 5 WRITE (3,100) X(J)                     00000490
: RATE1 = 0.0                             00000500

```

KP = 0	00000510
10 READ (4,*,END=50) RATE, EPS, STRESS	00000520
:	00000530
:	00000540
HAS STRAIN RATE CHANGED IN INPUT LIST?	00000550
:	00000560
IF (RATE .NE. RATE1) THEN DO	00000570
RATE1 = RATE	00000580
KP = KP + 1	00000590
KOUNT = 0	00000600
:	00000610
CORRECT SIGMAX TO PREVENT OVER / UNDER FLOW.	00000620
:	00000630
RATEB = DLOG10 (RATE ** X(2))	00000640
15 AX = X(3) * DLOG10 (SIGMAX(KP)) + RATEB	00000650
IF (AX .GT. 75.0D0) THEN DO	00000660
SIGMAX(KP) = SIGMAX(KP) - 0.5D0	00000670
GO TO 15	00000680
ENDIF	00000690
:	00000700
RATEB = RATE ** X(2)	00000710
RATED = RATE ** X(4)	00000720
ENDIF	00000730
KOUNT = KOUNT + 1	00000740
IF (EPS .EQ. 0.0D0) THEN DO	00000750
SIG1 = 0.0D0	00000760
ELSE DO	00000770
AX = SIG1	00000780
BX = SIGMAX(KP)	00000790
IF (KOUNT .EQ. 2) AX = STRESS / 1.3	00000800
SIG1 = ZEROIN (AX, BX, FUNCT, TOL)	00000810
ENDIF	00000820
WRITE (6,400) RATE, STRESS, EPS, SIG1	00000830
GO TO 10	00000840
50 STOP	00000850
100 FORMAT (1H ,1PD21.13)	00000860
200 FORMAT (20A4)	00000870
300 FORMAT (1H , 'TITLE : ',20A4)	00000880
400 FORMAT (1H ,5(1PD13.5))	00000890
END	00000900
DOUBLE PRECISION FUNCTION FUNCT(STRESS)	00000910
IMPLICIT REAL * 8 (A-H, O-Z)	00000920
DIMENSION X(5)	00000930
COMMON X, RATE, EPS, RATEB, RATED	00000940
TEMP1 = STRESS / X(5) / RATED	00000950
FUNCT = TEMP1 + X(1) * RATEB * STRESS ** X(3) - EPS	00000960
RETURN	00000970
END	00000980
:\$OPTIONS NOLIST	00000990
DOUBLE PRECISION FUNCTION ZEROIN(AX,BX,F,TOL)	00001000
DOUBLE PRECISION AX,BX,F,TOL	

DOUBLE PRECISION	A,B,C,D,E, EPS,FA,FB,FC,TOL1,XM,P,Q,R,S	00001010
DOUBLE PRECISION	DABS,DSIGN	00001020
	EPS = 1.0D0	00001030
10	EPS = EPS/2.0D0	00001040
	TOL1 = 1.0D0 + EPS	00001050
	IF (TOL1 .GT. 1.0D0) GO TO 10	00001060
	A = AX	00001070
	B = BX	00001080
	FA = F(A)	00001090
	FB = F(B)	00001100
20	C = A	00001110
	FC = FA	00001120
	D = B - A	00001130
	E = D	00001140
30	IF (DABS(FC) .GE. DABS(FB)) GO TO 40	00001150
	A = B	00001160
	B = C	00001170
	C = A	00001180
	FA = FB	00001190
	FB = FC	00001200
	FC = FA	00001210
40	TOL1 = 2.0D0*EPS*DABS(B) + 0.5D0*TOL	00001220
	XM = .5*(C - B)	00001230
	IF (DABS(XM) .LE. TOL1) GO TO 90	00001240
	IF (FB .EQ. 0.0D0) GO TO 90	00001250
	IF (DABS(E) .LT. TOL1) GO TO 70	00001260
	IF (DABS(FA) .LE. DABS(FB)) GO TO 70	00001270
	IF (A .NE. C) GO TO 50	00001280
	S = FB/FA	00001290
	P = 2.0D0*XM*S	00001300
	Q = 1.0D0 - S	00001310
	GO TO 60	00001320
50	Q = FA/FC	00001330
	R = FB/FC	00001340
	S = FB/FA	00001350
	P = S*(2.0D0*XM*Q*(Q - R) - (B - A)*(R - 1.0D0))	00001360
	Q = (Q - 1.0D0)*(R - 1.0D0)*(S - 1.0D0)	00001370
60	IF (P .GT. 0.0D0) Q = -Q	00001380
	P = DABS(P)	00001390
	IF ((2.0D0*P) .GE. (3.0D0*XM*Q - DABS(TOL1*Q))) GO TO 70	00001400
	IF (P .GE. DABS(0.5D0*E*Q)) GO TO 70	00001410
	E = D	00001420
	D = P/Q	00001430
	GO TO 80	00001440
70	D = XM	00001450
	E = D	00001460
80	A = B	00001470
	FA = FB	00001480
	IF (DABS(D) .GT. TOL1) B = B + D	00001490
	IF (DABS(D) .LE. TOL1) B = B + DSIGN(TOL1, XM)	00001500

```
FB = F(B)
IF ((FB*(FC/DABS(FC))) .GT. 0.0D0) GO TO 20
GO TO 30
90 ZEROIN = B
RETURN
END
```

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00001520
00001530
00001540
00001550
00001560
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*****00000010
PROGRAM NAME : MAP2                                *00000020
WRITTEN BY : J.F. BRANDEAU                          *00000030
COMPILER(S) : WATFIV (DOUBLE PRECISION)             *00000040
-----*00000050
PURPOSE : USE A SET OF OBSERVED POINTS AND COEFFICIENT VECTOR X TO *00000060
MATCH A PREDICTED VALUE OF STRAIN = F(STRESS, STRAIN RATE) TO EACH *00000070
OBSERVED POINT. READS FROM EXTERNAL FILE FOR COEFFICIENTS AND OBS- *00000080
ERVED VALUES, AND CAN READ COEFFICIENTS FROM TRAILING LIST (THESE *00000090
OVERRIDE EXTERNAL VALUES). SENDS OBSERVED POINTS AND PREDICTED *00000100
POINTS TO A FILE TO BE USED BY SAS. CAN ALSO DO SENSITIVITY ANALYSIS*00000110
WITHOUT CHANGING EXTERNAL VALUES OF COEFFICIENTS. *00000120
-----*00000130
VARIABLES : *00000140
X & COEFF : MANTISSAS AND EXPONENTS OF COEFFICIENT VECTOR. THESE ARE*00000150
COMBINED INTO X IN THE PROGRAM. *00000160
DELTA : FRACTIONAL CHANGE IN VARIABLE K FOR SENSITIVITY ANALYSIS. *00000170
SET THIS EQUAL TO ZERO TO GET TRUE COEFFICIENTS. *00000180
K : VARIABLE THAT WILL BE ALTERED BY AMOUNT (DELTA * X(K)). MUST BE *00000190
BETWEEN 1 AND 5 ALWAYS. *00000200
STRESS : OBSERVED VALUES OF STRESS (KSI). *00000210
RATE : OBSERVED VALUES OF STRAIN RATE (1/SEC). *00000220
EPS : OBSERVED VALUES OF STRAIN (IN/IN). *00000230
EPS1 : PREDICTED VALUE OF STRAIN RATE (IN/IN). *00000240
-----*00000250
I/O REQUIREMENTS : *00000260
FILE #1 : (OPTIONAL) X & COEFF VECTORS ON TWO RECORDS. *00000270
FILE #4 : OBSERVED VALUES OF RATE, EPS, STRESS IN THIS ORDER. THE *00000280
FIRST CARD MUST BE A TITLE. THE REMAINING CARDS CONTAIN *00000290
ONE OBSERVATION EACH. *00000300
FILE #5 : X & COEFF VECTORS ON TWO RECORDS. WILL ALWAYS BE READ. *00000310
-----*00000320
OPTIONS (FORM C$OPTIONS CCOMP=??????) : *00000330
3 : READ FROM DATA CARDS AT END OF PROGRAM LIST, FOLLOWING $DATA CARD*00000340
*****00000350
$OPTIONS CCOMP=0 *00000360
IMPLICIT REAL * 8 (A-H, N, O-Z) *00000370
DIMENSION X(5), COEFF(5) *00000380
INTEGER TITLE(20) *00000390

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00000400
00000410
00000420
00000430
00000440
00000450
00000460
00000470
00000480
00000490
00000500

```

READ (5,*) X	00000510
READ (5,*) COEFF	00000520
13 READ (1,*) X	00000530
13 READ (1,*) COEFF	00000540
DELTA = 0.0D0	00000550
K = 1	00000560
X(K) = X(K) * (1.0D0 + DELTA)	00000570
DO 5 J = 1, 5	00000580
X(J) = X(J) * COEFF(J)	00000590
5 WRITE (3,75) X(J)	00000600
READ (4,200) TITLE	00000610
WRITE (3,300) TITLE	00000620
10 READ (4,*,END=50) FATE, EPS, STRESS	00000630
...	00000640
CALCULATE PREDICTED STRAIN	00000650
...	00000660
TEMP1 = STRESS / X(5) / RATE ** X(4)	00000670
TEMP2 = STRESS ** X(3) * RATE ** X(2)	00000680
EPS1 = TEMP1 + X(1) * TEMP2	00000690
...	00000700
WRITE (6,100) RATE, STRESS, EPS, EPS1	00000710
GO TO 10	00000720
50 STOP	00000730
75 FORMAT (1H ,1PD20.12)	00000740
100 FORMAT (4D25.13)	00000750
200 FORMAT (20A4)	00000760
300 FORMAT (1H ,20A4)	00000770
END	00000780
5DATA	00000790
5.63 -0.589 6.19 3.20 3.10	00000800
1.0D-13 1.0D0 1.0D0 1.0D-2 1.0D3	00000810


```

//FORCE1 JOB DU.D08.AQ0221,BRANDEAU,T=(,10),M=(2,0) 00000010
// EXEC WATFIV 00000020
//GO.FT09F001 DD DSN=DU.D08.AQ0221.BRANDEAU.DATA.ONE,DISP=SHR 00000030
//GO.FT08F001 DD DSN=DU.D08.AQ0221.BRANDEAU.ATBDATA.ONE,DISP=SHR 00000040
//GO.SYSIN DD * 00000050
JOB 00000060
$OPTIONS CCOMP=2,NOEXT,NOCHECK,DEC 00000070
***** 00000080
SUBROUTINE FORCE IN MAIN PROGRAM FORM 00000090
THIS PROGRAM ANALYZES THE ATB OUTPUT DATA FOR DATA NEEDED IN THE 00000100
OPERATION OF THE BREAK PROGRAM. 00000110
1) THE TOP OF EACH TIME INCREMENT DATA SET IS FOUND 00000120
2) ROTATIONS AND ANGULAR VELOCITIES FOR TIME STEP ARE FOUND 00000130
3) DISPLACEMENTS AND LINEAR VELOCITIES ARE FOUND 00000140
4) JOINT FORCES AND TORQUES ARE FOUND 00000150
5) DATA IS WRITTEN TO PRINTER AND/OR DISK 00000160
A. OUTPUT TO DISK IS IN UNFORMATTED FORM 00000170
B. FOR EACH TIME INCREMENT, THE TIME (MS) AND DATA FOR EACH 00000180
LIMB IS OUTPUT. EACH LIMB 00000190
DATA SET FOR THAT TIME INCREMENT IS ON A RECORD, PRECEDED 00000200
BY THE IDENTIFYING NUMBER FOR THAT LIMB (1 - 8). 00000210
***** 00000220
KCON IS THE NUMBER OF "OTHER CONSTRAINT FORCES" 00000230
-1 = NONE 00000240
>0 = NUMBER OF ROWS OF DATA TO BE FOUND FOR EACH TIME STEP 00000250
00000260
POSIT = POINT OF ATTACHMENT RELATIVE TO C.G. OF SEGMENT IN SEGMENT 00000270
LOCAL Z-AXIAL COORDINATES. 00000280
CNSTRN(I,J) = FORCES IN INERTIAL COORDINATES (J = 1, 3) FOR SEGMENT I 00000290
(I = 1, KCON) 00000300
00000310
CHARACTER *4 IDUM,IPLAG 00000320
REAL D(8,30), VEH(18), POSIT(24), CNSTRN(8,3) 00000330
REAL * 8 DD(3), DA(3) 00000340
INTEGER KT3(8) 00000350
DATA KT3 / 8 * 1 /, CNSTRN /24 * 0.0/ 00000360
NT = 31 ; DLT = 0.01 00000370
IW = 3 ; IR = 1 ; IDISK1 = 9 ; IDISK2 = 8 00000380
WRITE (IW,100) 00000390
JP = 1 00000400
READ (1,*) KCON 00000410
KCON4 = KCON * 4 00000420
IF (KCON4 .EQ. 0) KCON4 = 1 00000430
POSIT(1) = 0 00000440
DO 2 I = 1, KCON4, 4 00000450
READ (1,*) POSIT(I), POSIT(I+1), POSIT(I+2), POSIT(I+3) 00000460
2 KT3(POSIT(I)) = 3 00000470
WRITE (IDISK2) NT, DLT, KCON4, (POSIT(I), I = 1, KCON4) 00000480
DO 4 J = 1, 200 00000490
READ (IDISK1,400) IDUM 00000500

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IF (IDUM .EQ. ' 5 H') GO TO 6	00000510
4 CONTINUE	00000520
6 DO 8 J = 1, 10	00000530
READ (IDISK1,420) I, W, X, Y, Z, A, B, C	00000540
IF (J .EQ. 3 .OR. J .EQ. 6) GO TO 8	00000550
23 WRITE (IW, 120) I, W, X, Y, Z, A, B, C	00000560
	00000570
OUTPUT TO DISK IN X-AXIAL COORDINATES AND CONSECUTIVE SEGMENT NUMBERS	00000580
	00000590
22 WRITE (IDISK2) JP, W, Z, X, Y, C, A, B	00000600
JP = JP + 1	00000610
8 CONTINUE	00000620
WRITE (IW, 130) (POSIT(KK), KK = 1, KCON4)	00000630
IP = 0	00000640
DO 80 I = 1, 1000	00000650
ON ERROR GOTO 75	00000660
IF (IP .GE. NT) THEN DO	00000670
PRINT,IP,' TIME STEPS FOUND'	00000680
STOP ; ENDIF	00000690
	00000700
FIND TOP OF DATA SET FOR EACH TIME INCREMENT	00000710
	00000720
13 READ (IDISK1 ,900, END = 90) IFLAG	00000730
IF (IFLAG .NE. 'MAIN') GO TO 13	00000740
BACKSPACE IDISK1	00000750
READ (IDISK1, 905) TIME	00000760
TIME = TIME / 1000.	00000770
	00000780
FIND ROTATIONS , ANGULAR VEL. AND ANGULAR ACC. FOR THIS TIME STEP	00000790
	00000800
IP = IP + 1	00000810
DO 20 II = 1, 15	00000820
READ (IDISK1, 1000) IDUM	00000830
IF (IDUM .NE. 'H ') GO TO 20	00000840
JP = 1	00000850
DO 15 J = 1, 10	00000860
READ (IDISK1 ,1100) (D(JP,KK),KK = 7,9), (DD(KK),KK = 1,3),	00000870
* (DA(KK), KK = 1,3)	00000880
IF (J .EQ. 3 .OR. J .EQ. 6) GO TO 15	00000890
DO 14 K4 = 1, 3	00000900
D(JP,K4+18) = SNGL (DA(K4))	00000910
14 D(JP,K4+9) = SNGL (DD(K4))	00000920
JP = JP + 1	00000930
15 CONTINUE	00000940
READ (IDISK1,800) (VEH(KK), KK = 7, 12)	00000950
GO TO 22	00000960
20 CONTINUE	00000970
	00000980
FIND LINEAR POSITION, VELOCITY AND ACCELERATION FOR THIS TIME STEP	00000990
	00001000

22 DO 40 II = 1, 15	00001010
READ (IDISK1,1000) IDUM	00001020
IF (IDUM.NE. 'H ') GO TO 40	00001030
JP = 1	00001040
DO 25 J = 1, 10	00001050
READ (IDISK1,2000) (D(JP,KK),KK = 1, 6), (D(JP,KK), KK = 22, 24)	00001060
IF (J.EQ. 3 .OR. J .EQ. 6) GO TO 25	00001070
JP = JP + 1	00001080
25 CONTINUE	00001090
READ (IDISK1,1000) IDUM	00001100
READ (IDISK1,2000) (VEH(KK), KK = 1, 6)	00001110
GO TO 50	00001120
40 CONTINUE	00001130
:	00001140
:	00001150
FIND U1 & U2 ARRAYS	00001160
:	00001170
50 DO 42 II = 1, 25	00001180
READ (IDISK1,400) IDUM	00001190
42 IF (IDUM.EQ. ' 5 H') GO TO 44	00001200
44 JP = 1	00001210
DO 46 JJ = 1, 10	00001220
READ (IDISK1,2000) (D(JP,KK), KK = 25, 30)	00001230
IF (JJ.EQ. 3 .OR. JJ.EQ. 6) GO TO 46	00001240
JP = JP + 1	00001250
46 CONTINUE	00001260
:	00001270
:	00001280
FIND FORCES AND TORQUES FOR THIS TIME INCREMENT	00001290
:	00001300
DO 70 IJ = 1, 50	00001310
READ (IDISK1,1000) IDUM	00001320
IF (IDUM.NE. 'HP ') GO TO 70	00001330
JP = 1	00001340
DO 60 JJ = 1, 10	00001350
READ (IDISK1,4000) (D(JP,KK), KK = 13, 18)	00001360
IF (JJ.EQ. 3 .OR. JJ.EQ. 6) GO TO 60	00001370
JP = JP + 1	00001380
60 CONTINUE	00001390
READ (IDISK1,4000) (VEH(KK), KK = 13, 18)	00001400
GO TO 71	00001410
70 CONTINUE	00001420
71 DO 74 II = 1, 20	00001430
READ (IDISK1,400) IDUM	00001440
IF (IDUM.NE. ' NO. ') GO TO 74	00001450
READ (IDISK1,400) IDUM	00001460
DO 72 IJ = 1, KCON	00001470
72 READ (IDISK1, 500) (CNSTRN (POSIT (4*IJ-3), IN), IN = 1, 3)	00001480
GO TO 75	00001490
74 CONTINUE	00001500
75 CONTINUE	

C	OUTPUT RESULTS	00001510
C	C2 = DISK OUTPUT (UNIT = IDISK2)	00001520
C	C3 = LINE PRINTER (UNIT = IW)	00001530
C2	WRITE (IDISK2) TIME, VEH	00001540
C3	PRINT, 'TIME =', TIME, ' VEHICLE =', VEH	00001550
C2	PRINT, 'TIME =', TIME, ' SEC'	00001560
	DO 85 J = 1, 8	00001570
	K3 = KT3(J)	00001580
C2	WRITE (IDISK2) J, K3, (D(J, KK), KK=1, 30), (CNSTRN(J, KK), KK=1, K3)	00001590
C3	WRITE (IW, 808) J, K3, (D(J, KK), KK=1, 30), (CNSTRN(J, KK), KK=1, K3)	00001600
	85 CONTINUE	00001610
C		00001620
	80 CONTINUE	00001630
	90 PRINT, 'END OF FILE REACHED ON UNIT', IDISK1	00001640
	PRINT, IP, ' TIME STEPS FOUND'	00001650
	STOP	00001660
C		00001670
C	INPUT FORMATS	00001680
	130 FORMAT (' EXTRA FORCE LOCATIONS :', F5.0, 3F12.3)	00001690
	400 FORMAT (1X, A4)	00001700
	500 FORMAT (25X, 3F15.5)	00001710
	420 FORMAT (I3, 13X, F7.3, 3X, 3F11.5, 5X, 3F8.3)	00001720
	800 FORMAT (/ , 11X, 3F9.4, 4X, 3(F7.3, 7X))	00001730
	900 FORMAT (7X, A4)	00001740
	905 FORMAT (57X, F8.3)	00001750
	1000 FORMAT (4X, A4)	00001760
	1100 FORMAT (11X, 3F9.4, 3X, 3D14.5, 3X, 3D14.5)	00001770
	2000 FORMAT (11X, 3F11.4, 3X, 3F12.5, 3X, 3F14.5)	00001780
	4000 FORMAT (15X, 3F11.4, 3X, 3F12.5)	00001790
C		00001800
C	OUTPUT FORMATS	00001810
	100 FORMAT (1H1, 10X, 'FORCES FROM ATB MODEL' /)	00001820
C3120	FORMAT (' I=', I2, ' W=', F7.3, ' XYZ=', 3F10.5, ' ABC=', 3F7.3)	00001830
C3808	FORMAT (1H , I2, I3, 2X, (T11, 6(E16.7, 3X)))	00001840
	END	00001850
	\$DATA	00001860
	2	00001870
	2 0.0 0.0 0.0	00001880
	4 0.0 0.0 0.0	00001890
	\$\$\$STOP	00001900
	\$\$\$END	00001910
	/*	00001920
	//*PW=BONE	00001930
	//	00001940

//FORCE2 JOB DU.D08.AQ0221,BRANDEAU,T=(,10),P=45,M=(2,0)	00000010
// EXEC WATFIV	00000020
//GO.FT09F001 DD DSN=DU.D08.AQ0221.BRANDEAU.DATA.TWO,DISP=SHR	00000030
//GO.FT08F001 DD DSN=DU.D08.AQ0221.BRANDEAU.ATBDATA.TWO,DISP=SHR	00000040
//GO.SYSIN DD *	00000050
\$JOB	00000060
\$OPTIONS NOEXT,CCOMP=2,NOCHECK,DEC	00000070
\$OPTIONS NOLIST	00000080
CHARACTER * 10 IDUM, DUMB	00000090
CHARACTER * 3 ISEG1, ISEG2	00000100
REAL PANEL (32,8,3,6), SEGMENT (32,8,3,6), X1 (3), X2 (3)	00000110
INTEGER CHEKP (32,8), CHEKS (32,8), ID(3), UCOUNT, NP(4)	00000120
CHARACTER ITEST*3(8) / 'RUL', 'RLL', 'LUL', 'LLL', 'RUA', 'RLA', 'LUA'	00000130
* , 'LLA' /	00000140
DATA CHEKP, CHEKS / 512 * 0 /	00000150
DATA PANEL, SEGMENT / 9216 * 0.0 /	00000160
DATA NP / 58, 92, 92, 92 /	00000170
*****	00000180
EXPLANATION OF VARIABLES --	00000190
PANEL (I,J,K,L) AND SEGMENT (I,J,K,L) CONTAIN CONTACT DATA	00000200
I = TIME STEP	00000210
J = LIMB OR MEMBER NUMBER	00000220
K = CONTACT NUMBER	00000230
L = 1 TO 6	00000240
L = 1 IS THE NUMBER OF THE PANEL OR SEGMENT CONTACTED	00000250
-- SEGMENT NUMBERS ARE IN ATB MODEL CODE, NOT BREAK CODE	00000260
L = 2 IS THE NORMAL FORCE	00000270
L = 3 IS THE FRICTION FORCE	00000280
L = 4 TO 6 ARE THE X,Y,Z COORDINATES OF THE CONTACT POINT	00000290
SEGMENT CONTACT POINTS ARE IN ATB LOCAL COORDINATES	00000300
PANEL CONTACT POINTS ARE IN ATB INERTIAL COORDINATES	00000310
CHEKP (I,J) AND CHEKS (I,J) ARE CONTACT COUNTERS FOR EACH LIMB	00000320
AND TIME STEP	00000330
I = TIME STEP	00000340
J = LIMB OR MEMBER NUMBER	00000350
THE VALUE STORED IN LOCATION CHEKP OR CHEKS (I,J) IS THE NUMBER	00000360
OF CONTACTS FOR THAT LIMB AND TIME STEP THAT HAD NON-ZERO	00000370
FORCES. CONTACTS WITH ZERO FORCES ARE NOT STORED IN THE ARRAY	00000380
OR WRITTEN TO THE DISK OR PRINTER.	00000390
NP = THE NUMBER OF RECORDS THAT OCCUR BETWEEN PAGE HEADERS	00000400
ON THE ATB OUTPUT FILE. THIS MUST BE CHANGED AS THE	00000410
TIME STEP THEY USE CHANGES. THIS IS NOT THE SAME BETWEEN	00000420
EACH HEADER BLOCK.	00000430
UCOUNT = THE NUMBER OF CONTACT FILES TO BE LOOKED FOR. THE	00000440
NUMBER OF FILES FOUND IS COUNTED, NOT THE NUMBER OF	00000450
INDIVIDUAL CONTACTS. UCOUNT DOES NOT INCLUDE FILES HAVING	00000460
	00000470
	00000480
	00000490
	00000500

ALL ZERO FORCES OR SEGMENTS THAT ARE NOT OF INTEREST.	00000510
TMAX = MAXIMUM TIME TO BE FOUND.	00000520
FORMAT # 3416 MUST ALSO BE CHANGED TO SKIP THE PROPER NUMBER OF	00000530
RECORDS IN EACH FILE IF THE FILE IS OF NO INTEREST.	00000540
*****	00000550
ON ERROR GOTO 255	00000560
DLT = 0.01 ; NT = 31; TMAX = 300.0	00000570
IW = 3 ; IR = 1 ; IDISK1 = 9 ; IDISK2 = 8	00000580
WRITE (IW, 100)	00000590
IP = 0 ; IDT = INT (10000. * DLT) ; ICOUNT = 0 ; UCOUNT = 9	00000600
DO 200 I = 1, 500	00000610
READ (IDISK1, 103, END=255) IDUM	00000620
IF (IDUM .EQ. 'SEGMENT NO') GO TO 210	00000630
IF (IDUM .NE. 'VEHICLE PA') GO TO 200	00000640
----- PANEL VS. SEGMENT CONTACT -----	00000650
READ (IDISK1, 102) IPAN1, ISEG1, IPAN2, ISEG2	00000660
IFLAG1 = IFLAG2 = 0	00000670
CHECK FOR SEGMENT OF INTEREST	00000680
DO 110 J = 1, 8	00000690
IF (ISEG1 .NE. ITEST(J) .AND. ISEG2 .NE. ITEST(J)) GO TO 110	00000700
IF (ISEG1 .NE. ITEST(J)) GO TO 105	00000710
JHOLD1 = J ; IFLAG1 = 1	00000720
IF (ISEG2 .NE. ITEST(J)) GO TO 109	00000730
JHOLD2 = J ; IFLAG2 = 2	00000740
IFLAG3 = IFLAG1 + IFLAG2	00000750
IF (IFLAG3 - 3) 110, 112, 110	00000760
CONTINUE	00000770
IF (IFLAG1 + IFLAG2) 111, 111, 112	00000780
SKIP ENTIRE FILE	00000790
111 READ (IDISK1, 3416) DUMB	00000800
GO TO 200	00000810
112 READ (IDISK1, 113) DUMB	00000820
NUMPAG = NP(1)	00000830
ICOUNT = ICOUNT + 1	00000840
DO 155 J = 1, 11	00000850
IF (J .EQ. 1) GO TO 120	00000860
READ (IDISK1, 114) DUMB	00000870
DO 150 JL = 1, NUMPAG	00000880
READ (IDISK1, 115) T, FN1, FF1, X1, FN2, FF2, X2	00000890
IT = INT (10. * T)	00000900
	00000910
	00000920
	00000930
	00000940
	00000950
	00000960
	00000970
	00000980
	00000990
	00001000

	ITT = IT / IDT + 1	00001010
	IF ((IT/IDT * IDT) .NE. IT) GO TO 150	00001020
	IF (IFLAG2) 500, 130, 129	00001030
29	IF (FN2 .EQ. 0.0 .AND. FF2 .EQ. 0.0) GO TO 131	00001040
	CHEKP (ITT, JHOLD2) = TEMPCT = CHEKP (ITT, JHOLD2) + 1	00001050
	PANEL (ITT, JHOLD2, TEMPCT, 1) = FLOAT (IPAN2)	00001060
	PANEL (ITT, JHOLD2, TEMPCT, 2) = FN2	00001070
	PANEL (ITT, JHOLD2, TEMPCT, 3) = FF2	00001080
	DO 132 K4 = 1, 3	00001090
32	PANEL (ITT, JHOLD2, TEMPCT, K4+3) = X2 (K4)	00001100
31	IF (IFLAG1) 500, 140, 130	00001110
30	IF (FN1 .EQ. 0.0 .AND. FF1 .EQ. 0.0) GO TO 140	00001120
	CHEKP (ITT, JHOLD1) = TEMPCT = CHEKP (ITT, JHOLD1) + 1	00001130
	PANEL (ITT, JHOLD1, TEMPCT, 1) = FLOAT (IPAN1)	00001140
	PANEL (ITT, JHOLD1, TEMPCT, 2) = FN1	00001150
	PANEL (ITT, JHOLD1, TEMPCT, 3) = FF1	00001160
	DO 133 K4 = 1, 3	00001170
133	PANEL (ITT, JHOLD1, TEMPCT, K4+3) = X1 (K4)	00001180
140	IF (ITT .GE. NT .OR. T .EQ. TMAX) GO TO 200	00001190
150	CONTINUE	00001200
	NUMPAG = NP(J+1)	00001210
55	CONTINUE	00001220
200	CONTINUE	00001230
		00001240
205	READ (IDISK1, 103, END = 255) IDUM	00001250
	IF (IDUM .NE. 'SEGMENT NO') GO TO 260	00001260
	----- SEGMENT VS. SEGMENT CONTACT -----	00001270
		00001280
		00001290
110	BACKSPACE IDISK1	00001300
	READ (IDISK1, 101) IDUM, IHOLD1, ISEG1, IHOLD2, ISEG2	00001310
	IFLAG1 = IFLAG2 = 0	00001320
	JHOLD1 = JHOLD2 = 0	00001330
		00001340
	CHECK FOR SEGMENT(S) OF INTEREST	00001350
		00001360
	DO 220 J = 1, 8	00001370
	IF (ISEG1 .NE. ITEST(J) .AND. ISEG2 .NE. ITEST(J)) GO TO 220	00001380
	IF (ISEG1 .NE. ITEST(J)) GO TO 218	00001390
	JHOLD1 = J ; IFLAG1 = 1	00001400
	GO TO 220	00001410
118	IF (ISEG2 .NE. ITEST(J)) GO TO 219	00001420
	JHOLD2 = J ; IFLAG2 = 2	00001430
119	IFLAG3 = IFLAG1 + IFLAG2	00001440
	IF (IFLAG3 - 3) 220, 222, 220	00001450
220	CONTINUE	00001460
		00001470
	IF (IFLAG2 + IFLAG1) 500, 221, 222	00001480
		00001490
	SKIP ENTIRE FILE	00001500

		00001510
221	READ (IDISK1,3416) DUMB	00001520
	GO TO 260	00001530
222	READ (IDISK1,113) DUMB	00001540
	NUMPAG = NP(1)	00001550
	ICOUNT = ICOUNT + 1	00001560
	ITT = 1	00001570
	DO 252 J = 1, 11	00001580
	IF (J .EQ. 1) GO TO 224	00001590
	READ (IDISK1,223) DUMB	00001600
224	DO 250 JL = 1, NUMPAG	00001610
	READ (IDISK1, 225, END=255) T, FN1, PF1, X1, X2	00001620
	IF (FN1 .EQ. 0.0 .AND. PF1 .EQ. 0.0) GO TO 240	00001630
	IT = INT (10. * T)	00001640
	ITT = IT / IDT + 1	00001650
	IF ((IT / IDT * IDT) .NE. IT) GO TO 240	00001660
	IF (IFLAG2) 500, 230, 226	00001670
226	CHEKS (ITT, JHOLD2) = TEMPCT = CHEKS (ITT, JHOLD2) + 1	00001680
	SEGNET (ITT, JHOLD2, TEMPCT, 1) = FLOAT (JHOLD1)	00001690
	SEGNET (ITT, JHOLD2, TEMPCT, 2) = FN1	00001700
	SEGNET (ITT, JHOLD2, TEMPCT, 3) = PF1	00001710
	DO 227 K4 = 1, 3	00001720
227	SEGNET (ITT, JHOLD2, TEMPCT, K4+3) = X2 (K4)	00001730
	IF (IFLAG1) 500, 240, 230	00001740
230	CHEKS (ITT, JHOLD1) = TEMPCT = CHEKS (ITT, JHOLD1) + 1	00001750
	SEGNET (ITT, JHOLD1, TEMPCT, 1) = FLOAT (JHOLD2)	00001760
	SEGNET (ITT, JHOLD1, TEMPCT, 2) = FN1	00001770
	SEGNET (ITT, JHOLD1, TEMPCT, 3) = PF1	00001780
	DO 232 K4 = 1, 3	00001790
232	SEGNET (ITT, JHOLD1, TEMPCT, K4+3) = X1 (K4)	00001800
240	IF (ITT. GE. NT .OR. T .EQ. TMAX) GO TO 260	00001810
250	CONTINUE	00001820
	NUMPAG = NP(J+1)	00001830
252	CONTINUE	00001840
		00001850
260	IF (ICOUNT .LT. UCOUNT) GO TO 205	00001860
		00001870
	OUTPUT DATA	00001880
		00001890
255	DO 1000 J3 = 1, NT	00001900
	TIME = FLOAT (J3-1) * DLT	00001910
2	WRITE (3,2200) TIME	00001920
3	WRITE (IDISK2) TIME	00001930
	DO 1000 J4 = 1, 8	00001940
	ID(1) = J4	00001950
	IF (CHEKP(J3,J4) .EQ. 0) THEN DO	00001960
	JPAN = ID2 = ID(2) = 1	00001970
	ELSE DO	00001980
	JPAN = 6 ; ID(2) = 6 * CHEKP (J3,J4)	00001990
	ID2 = ID(2) / 6	00002000

ENDIF	00002010
IF (CHEKS(J3,J4) .EQ. 0) THEN DO	00002020
JSEG = ID3 = ID(3) = 1	00002030
ELSE DO	00002040
JSEG = 6 ; ID(3) = 6 * CHEKS(J3,J4)	00002050
ID3 = ID(3) / 6	00002060
ENDIF	00002070
2 WRITE (3,2000) ITEST(ID(1)), ID(1), ID(2),	00002080
2 \$ ((PANEL(J3,J4,J5,J6), J6 = 1, JPAN), J5 = 1, ID2)	00002090
2 WRITE (3,2100) ID(3), ((SEGNET(J3,J4,J5,J6),J6=1,JSEG),J5=1,ID3)	00002100
3 WRITE(IDISK2) ID, ((PANEL(J3,J4,J5,J6),J6=1,JPAN),J5=1,ID2),	00002110
3 * ((SEGNET(J3,J4,J5,J6),J6=1,JSEG),J5=1,ID3)	00002120
1000 CONTINUE	00002130
STOP	00002140
500 PRINT, 'THE VALUE OF THE FLAG IS L.T. ZERO ---ERROR ---'	00002150
STOP	00002160
100 FORMAT (1H1, 10X, 'FORCES FROM ATB MODEL'//)	00002170
101 FORMAT (44X,A10,2X,I2,2X,A3,19X,I2,2X,A3)	00002180
102 FORMAT (/ , 20X, I2, 40X, A3, 15X, I2, 40X, A3)	00002190
103 FORMAT (44X,A10)	00002200
3416 FORMAT (180(/ ,A10)	00002210
113 FORMAT (///A10)	00002220
114 FORMAT (11(/ ,A10)	00002230
115 FORMAT (F9.3,9X,2F9.2,9X,3F8.3,9X,2F9.2,9X,3F8.3)	00002240
223 FORMAT (10(/ ,A10)	00002250
225 FORMAT (F9.3,9X,2F9.2,9X,3F8.3,2X,3F8.3)	00002260
2000 FORMAT (1H , A4, 2I5, 5X, F5.0, 5F12.3)	00002270
2100 FORMAT (1H , I14, 5X, F5.0, 5F12.3)	00002280
2200 FORMAT ('-TIME =',F6.3,' MSEC')	00002290
END	00002300
DATA	00002310
END	00002320
STOP	00002330
/*	00002340
/*PW=BONE	00002350
//	00002360
	00002370

//ALF,PA JOB DU.D08.AQ0221,BRANDEAU,M=(2,0)	00000010
// EXEC WATFIV	00000020
//GO.FT06F001 DD DSN=DU.D08.AQ0221.BRANDEAU.ATBDATA.ONE,DISP=SHR	00000030
//GO.FT07F001 DD DSN=DU.D08.AQ0221.BRANDEAU.ATBDATA.TWO,DISP=SHR	00000040
//GO.FT09F001 DD DSN=DU.D08.AQ0221.BRANDEAU.ATBDATA.FINAL,DISP=SHR	00000050
//GO.SYSIN DD *	00000060
!JOB	00000070
!OPTIONS NOEXT,NOCHECK,CCOMP=0	00000080
REAL VEH(13), FORCE(8,30), PANEL(8,24), INSEG(8,24), TIME	00000090
REAL DUMMY(7), OUTSEG(8,72), POSIT(24), CNSTRN(8,3)	00000100
INTEGER NT, LIMB, ID(8,3), KT(8)	00000110
READ (6) NT, DLT, KCON4, (POSIT(I), I = 1, KCON4)	00000120
WRITE (9) NT, DLT, KCON4, (POSIT(I), I = 1, KCON4)	00000130
:	00000140
: READ AND WRITE SEGMENT *, MASS, INERTIA, AND SEMI-MAJOR AXES.	00000150
:	00000160
DO 10 I = 1, 8	00000170
READ (6) J, DUMMY	00000180
10 WRITE (9) J, DUMMY	00000190
:	00000200
: BEGIN LOOP FOR ALL REMAINING DATA TO BE COMBINED	00000210
:	00000220
DO 100 I = 1, NT	00000230
READ (6) VEH	00000240
READ (7) TIME	00000250
PRINT, 'TIME = ', TIME	00000260
WRITE (9) VEH	00000270
:	00000280
: READ IN ALL DATA FOR THIS TIME STEP	00000290
:	00000300
DO 40 J = 1, 8	00000310
READ (6) LIMB, K3, (FORCE(J,K), K = 1,30), (CNSTRN(J,K), K=1,K3)	00000320
KT(J) = K3	00000330
:	00000340
: CONVERT ROTATIONS FROM DEGREES TO RADIANS	00000350
:	00000360
DO 20 K = 7,9	00000370
20 FORCE(J,K) = FORCE(J,K) / 57.29578	00000380
READ (7) ID(J,1), ID2, ID3, (PANEL(J,KK), KK = 1, ID2),	00000390
\$ (INSEG(J,KK), KK = 1, ID3)	00000400
ID(J,2) = ID2 ; ID(J,3) = ID3	00000410
IF (LIMB.NE. ID(J,1)) THEN DO	00000420
PRINT, 'LIMB NOS. NOT EQUAL AT STEP ', J	00000430
PRINT, 'LIMB NO. FROM UNIT 6 =', LIMB	00000440
PRINT, 'LIMB NO. FROM UNIT 7 =', ID(J,1)	00000450
PRINT, 'STOPPING NOW'	00000460
STOP	00000470
ENDIF	00000480
40 CONTINUE	00000490
:	00000500

COMBINE DATA FOR EACH CONTACTED SEGMENT SO THAT RELATIVE	00000510
VELOCITIES CAN BE CALCULATED. INCREASE SEGMENT DATA FROM	00000520
6 TO 18 ITEMS.	00000530
	00000540
DO 60 J = 1, 8	00000550
ID3 = ID(J,3) ; ID2 = ID(J,2) ; OUTSEG(J,1) = 0.0	00000560
IF (ID3 .EQ. 1) GO TO 55	00000570
DO 50 K = 1, ID3, 6	00000580
NUM = IPIX(INSEG(J,K))	00000590
K1 = 3 * K - 2 ; K2 = K1 + 17 ; K3 = K1 + 6 ; K4 = K1 + 5	00000600
DO 44 L = K1, K4	00000610
44 OUTSEG(J,L) = INSEG(J,K+L-K1)	00000620
IF (NUM .EQ. 0) THEN DO	00000630
DO 45 L = K3, K4	00000640
45 OUTSEG(J,L) = 0.0	00000650
ELSE DO	00000660
	00000670
FIND PROPER LOCATION IN SEGMENT "NUM" FILE	00000680
	00000690
ID2 = 1	00000700
WHILE (IPIX(INSEG(NUM,ID2)) .NE. J) DO	00000710
ID2 = ID2 + 6	00000720
ENDWHILE	00000730
	00000740
DO 48 L = 1, 3	00000750
48 OUTSEG(J,K1+L+5) = FORCE(NUM,L+3)	00000760
DO 49 L = 15, 17	00000770
49 OUTSEG(J,K1+L) = INSEG(NUM,ID2+L-12)	00000780
ENDIF	00000790
50 CONTINUE	00000800
ID3 = ID3 / 6 * 18	00000810
	00000820
NEGATE "OTHER FORCES" FOR EQUILIBRIUM	00000830
	00000840
55 K3 = KT(J)	00000850
WRITE (9) ID(J,1), ID2, ID3, K3, (FORCE(J,KK), KK = 1, 30),	00000860
\$ (PANEL(J,KK),KK = 1, ID2), (OUTSEG(J,KK), KK = 1, ID3)	00000870
\$,(-CNSTRN(J,KK), KK = 1, K3)	00000880
12 WRITE (3,300) ID(J,1), ID2, (PANEL(J,KK), KK = 1, ID2)	00000890
12 WRITE (3,200) ID3, (OUTSEG(J,KK), KK = 1, ID3)	00000900
12 IF (K3 .GT. 1) WRITE (3,150) K3, (-CNSTRN(J,KK), KK = 1,K3)	00000910
60 CONTINUE	00000920
100 CONTINUE	00000930
STOP	00000940
2300 FORMAT (' LIMB =',I2,I3,5X,(2F5.0,5F8.2,5X))	00000950
2200 FORMAT (' SEGS',I3,(F5.0,1X,2F6.2,2X,15F7.1))	00000960
2150 FORMAT ('EXTRA CONTACTS =',I4,3F12.4)	00000970
END	00000980
DATA	00000990
END	00001000

```

:SOPTIONS DEC,CCOMP=1                                00000010
: PROGRAM NAME : CONTACT                                00000020
  REAL VEH(12), FORCE(30), PANEL(24), SEGMENT(72), PLANE(33) 00000030
  REAL ABC(24), XYZ(24), TIME, INERT(24), WEIGHT(8), D1(8) 00000040
  REAL RADS(3), OMEGA(3), THOLD(3), OMEGA2(3), RADS2(3)      00000050
  REAL XHOLD(3), XTEMP(3), TEMP(3), WORK(6), POSIT(24), CNSTEN(6) 00000060
  CHARACTER SEG*3(8) /'RUL','RLL','LUL','LLL','RUA','RLA','LUA', 00000070
  * 'LLA' / 00000080
  INTEGER NT, LIMB, NPAN, NSEG, KT, JS, JS2, JS3, LIMB0, LIMB1, KKK 00000090
  INTEGER KK, J1, J2, J, I, K, ICHEK, KS, KP, NUM, NUM0, NCON, KCON4 00000100
  COMMON /TRANS/ ICHEK 00000110
  INTEGER YES(8) 00000120
  DATA YES /8 * 0 / 00000130
  REAL GINCH / 386.0886 / 00000140
  DATA PLANE /-.1104,0.0,-.9939, .9744,0.0,-.2249, 00000150
  * 0.0,0.0,-1.0, .9745,0.0,-.2245, .9191,0.0,.3939, 00000160
  * -.0499,0.0,.9988, -1.0,0.0,0.0, 0.0,-1.0,0.0, 00000170
  * 0.0,1.0,0.0, .9720,0.0,-.2350, -.6428,0.0,-.7660 / 00000180
  DATA D1 /8.8, 7.93, 8.8, 7.93, 5.44, 7.94, 5.44, 7.94 / 00000190
  EQUIVALENCE (RADS, FORCE(7)), (OMEGA, FORCE(10)) 00000200
  READ (5) NT, DLT, KCON4, (POSIT(I), I = 1, KCON4) 00000210
  IF (KCON4 .EQ. 1) GO TO 4 00000220
: 00000230
: ROTATE "OTHER CONSTRAINT FORCE" LOCATION TO X-AXIAL COORDINATES 00000240
: WITH THE ORIGIN AT THE PROXIMAL JOINT 00000250
: 00000260
: DO 3 I = 1, KCON4, 4 00000270
:   CALL CHANGE (POSIT, I+1, 24, D1(POSIT(I))) 00000280
: 3 YES(POSIT(I)) = I + 1 00000290
: 00000300
: 4 WRITE (9) NT, DLT, KCON4, (POSIT(I), I = 1, KCON4) 00000310
:   WRITE (9) D1(1), D1(2), D1(5), D1(6) 00000320
: 00000330
: READ SEGMENT WEIGHTS, INERTIAS, AND SEMI-MAJOR AXES IN LOCAL X-AXIAL 00000340
: SEGMENT COORDINATES. 00000350
: 00000360
: J1 = -2 00000370
: DO 5 J = 1, 8 00000380
: J1 = J1 + 3 00000390
: J2 = J1 + 2 00000400
: READ (5) I, WEIGHT(J), (INERT(K), K=J1,J2), (ABC(K), K = J1, J2) 00000410
: WRITE (9) I, WEIGHT(J), (ABC(K), K=J1,J2) 00000420
: 00000430
: SQUARE SEMI-MAJOR AXES OF ELLIPSOIDS FOR LATER USE 00000440
: 00000450
: DO 5 K = J1, J2 00000460
: 5 ABC(K) = ABC(K) * ABC(K) 00000470
: 00000480
: DO 350 KKK = 1, NT 00000490
: READ (5) TIME, VEH 00000500

```

01	PRINT, 'TIME =', TIME	00000510
	WRITE (9) TIME	00000520
	DO 350 KK = 1, 8	00000530
	READ (5) LIMB, NPAN, NSEG, NCON, FORCE, (PANEL(I), I = 1, NPAN)	00000540
	* , (SEGNET(I), I = 1, NSEG), (CNSTRN(I), I = 1, NCON)	00000550
	LIMBO = 3 * LIMB - 3	00000560
		00000570
03	PRINT, '*****'	00000580
03	PRINT, 'SEGMENT IS ', LIMB, ' OR ', SEG(LIMB)	00000590
03	PRINT, '*****'	00000600
03	PRINT, 'ROTATION ANGLES (RADIAN)'	00000610
03	WRITE (3,500) (FORCE(I), I = 7, 9)	00000620
	ICHECK = -1	00000630
	KS = 0	00000640
	KP = 0	00000650
	IF (NSEG .EQ. 1) GO TO 50	00000660
	-----	00000670
	SEGMENT - SEGMENT CONTACT	00000680
	-----	00000690
	SEGMENT CONTACT POINTS IN SEGMENT COORDINATES	00000700
		00000710
	KS = NSEG / 18	00000720
	DO 40 J = 1, KS	00000730
	JXYZ = 6 * J - 5	00000740
	JS = 1 + (J-1) * 18	00000750
	JS2 = JS + 1	00000760
	JS3 = JS + 2	00000770
	NUM = IFIX (SEGNET(JS))	00000780
03	PRINT, ' '	00000790
03	PRINT, 'SEGMENT', LIMB, ' CONTACTING SEGMENT', NUM	00000800
03	PRINT, 'NORMAL FORCE =', SEGNET(JS2)	00000810
03	PRINT, 'FRICTION FORCE =', SEGNET(JS3)	00000820
03	PRINT, 'CONTACT AT ATB LOCAL XYZ', (SEGNET(JS+I), I = 3, 5)	00000830
	-----	00000840
	NORMAL CONTACT FORCES	00000850
	-----	00000860
		00000870
	FIND NORMAL TO ELLIPSOID AT POINT OF CONTACT	00000880
		00000890
	HOLD = 0.0	00000900
	DO 10 I = 1, 3	00000910
	HOLD2 = SEGNET(JS3+I) / ABC(LIMBO+I)	00000920
	TEMP(I) = HOLD2	00000930
	WORK(I+3) = HOLD2	00000940
10	HOLD = HOLD + HOLD2 * HOLD2	00000950
	HOLD = SQRT (HOLD)	00000960
		00000970
	MULTIPLY UNIT NORMAL BY NORMAL FORCE SCALAR - STORE IN "WORK(1-3)"	00000980
		00000990
	DO 15 I = 1, 3	00001000

```

15 WORK(I) = -TEMP(I) * SEGNET(JS2) / HOLD
   IF (SEGNET(JS3) .EQ. 0.0) GO TO 39

```

 FRICTION CONTACT FORCES

```

: ASSIGN DATA FOR SEGMENT "NUM" TO STORAGE VECTORS
:

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```

: DO 20 I = 1, 3
:   JSI = JS + I
:   XTEMP(I) = SEGNET(JSI + 14)
:   THOLD(I) = SEGNET(JSI + 5)
:   RADS2(I) = SEGNET(JSI + 8)
:   OMEGA2(I) = SEGNET(JSI + 11)
20 TEMP(I) = SEGNET(JSI + 2)

```

```

: CONSTRUCT RELATIVE VELOCITY VECTOR IN SEGMENT "LIMB" COORDINATES
: FOR SEGMENT "LIMB" CONTACTING SEGMENT "NUM".
: VECTORS "OMEGA2", "RADS2", "THOLD" & "XTEMP" CONTAIN DATA FOR
: SEGMENT "NUM".
:

```

```

:   CALL CROSS (OMEGA2, XTEMP, XHOLD)
:9 PRINT,'W2 CROSS R2=',XHOLD
:   CALL ROT (XHOLD, 1, 3, RADS2, -1)
:9 PRINT,'SAME VECTOR ROTATED INTO INERTIAL',XHOLD
:   ICHEK = -1
:   CALL CROSS (OMEGA, TEMP, XTEMP)
:9 PRINT,'W CROSS R=',XTEMP
:   DO 25 I = 1, 3
25 THOLD(I) = FORCE(I+3) - THOLD(I) - XHOLD(I)
:   CALL ROT (THOLD, 1, 3, RADS, +1)
:

```

```

:   DO 30 I = 1, 3
:     THOLD(I) = THOLD(I) + XTEMP(I)
30 TEMP(I) = WORK(I+3)
:9 PRINT,'RELATIVE VELOCITY VECTOR IN LOCAL',THOLD
:

```

```

: PROJECT VELOCITY VECTOR ONTO TANGENT PLANE TO SEGMENT "LIMB"
:

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```

:   CALL VECTOR (TEMP, THOLD, XHOLD)
:9 PRINT,'SAME PROJECTED INTO PLANE OF SEG.',XHOLD
:

```

```

: MULTIPLY PROJECTED VELOCITY BY FRICTION SCALAR AND COMBINE
: ALL FORCES INTO "WORK (1-3)"
:

```

```

:   DO 35 I = 1, 3
35 WORK(I) = WORK(I) + XHOLD(I) * SEGNET(JS3)
: CONVERT SEGMENT Z-AXIAL COORDINATES TO X-AXIAL
:
39 XYZ(JXYZ) = SEGNET(JS+5) + D1(LIMB)

```

```

00001010
00001020
00001030
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00001060
00001070
00001080
00001090
00001100
00001110
00001120
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00001150
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00001190
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00001500

```

XYZ(JXYZ+1) = SEGMENT(JS+3)	00001510
XYZ(JXYZ+2) = SEGMENT(JS+4)	00001520
XYZ(JXYZ+3) = WORK(3)	00001530
XYZ(JXYZ+4) = WORK(1)	00001540
XYZ(JXYZ+5) = WORK(2)	00001550
40 CONTINUE	00001560
50 IF (NPAN .EQ. 1) GO TO 130	00001570

SEGMENT - PANEL CONTACT	00001580

PANEL CONTACT DATA IS IN INERTIAL COORDINATES.	00001600
KP = NPAN / 6	00001610
K1 = KS + 1	00001620
K2 = K1 + KP - 1	00001630
DO 120 J1 = K1, K2	00001640
JXYZ = 6 * J1 - 5	00001650
J = J1 - KS	00001660
JS = 1 + (J-1) * 6	00001670
JS2 = JS + 1	00001680
JS3 = JS + 2	00001690
	00001700
	00001710
	00001720
CORRECT PANEL CONTACT POINT FOR VEHICLE MOTION	00001730
	00001740
DO 55 I2 = 1, KP	00001750
DO 55 I = 1, 3	00001760
NUM = 6 * (J-1) + I + 3	00001770
55 PANEL(NUM) = PANEL(NUM) + VEH(I)	00001780
13 NUM = IFIX(PANEL(JS))	00001790
13 PRINT, ' '	00001800
13 PRINT, 'SEGMENT', LIMB, ' CONTACTING PANEL', NUM	00001810
13 PRINT, 'NORMAL FORCE =', PANEL(JS2)	00001820
13 PRINT, 'FRICTION FORCE =', PANEL(JS3)	00001830
13 PRINT, 'CONTACT AT INERTIAL XYZ', (PANEL(JS+I), I = 3, 5)	00001840
	00001850
FIND VECTOR FROM CENTER OF ELLIPSOID TO CONTACT POINT	00001860
IN INERTIAL COORDINATES.	00001870
	00001880
DO 60 I = 1, 3	00001890
TEMP(I) = PANEL(JS3+I) - FORCE(I)	00001900
60 THOLD(I) = TEMP(I)	00001910
15 PRINT, 'INERTIAL CONTACT VECTOR BEFORE TRANSFORMATION'	00001920
15 WRITE (3,500) TEMP	00001930
	00001940
TRANSFORM CONTACT VECTOR FROM INERTIAL TO SEGMENT COORDINATES	00001950
	00001960
CALL ROT (TEMP, 1, 3, RADS, 1)	00001970
15 PRINT, 'AFTER TRANSFORMATION TO SEGMENT LOCAL'	00001980
15 WRITE (3,500) TEMP	00001990
15 PRINT, ' '	00002000

STORE CONTACT POINT IN X-AXIAL COORDINATES	00002010
	00002020
	00002030
XYZ(JXYZ) = TEMP(3) + D1(LIME)	00002040
XYZ(JXYZ+1) = TEMP(1)	00002050
XYZ(JXYZ+2) = TEMP(2)	00002060
-----	00002070
NORMAL CONTACT FORCES	00002080
-----	00002090
NUM = IPIX (PANEL(JS))	00002100
NUM0 = 3 * NUM - 3	00002110
DO 70 I = 1, 3	00002120
TEMP(I) = PLANE(NUM0+I)	00002130
WORK(I+3) = 0.0	00002140
XTEMP(I) = OMEGA(I)	00002150
70 WORK(I) = TEMP(I) * PANEL(JS2)	00002160
	00002170
IF (PANEL(JS3) .EQ. 0.0) GO TO 95	00002180
-----	00002190
FRICTION CONTACT FORCES	00002200
-----	00002210
FIND VELOCITY VECTOR OF CONTACT POINT IN INERTIAL COORDINATES.	00002220
	00002230
	00002240
CALL ROT2 (XTEMP, 1, 3, -1)	00002250
CALL CROSS (XTEMP, THOLD, XHOLD)	00002260
PRINT, 'ANGULAR VELOCITY OF C.G.'	00002270
WRITE (3,500) XTEMP	00002280
PRINT, 'LINEAR VELOCITY DUE TO ROTATION -- OMEGA CROSS R'	00002290
WRITE (3,500) XHOLD	00002300
PRINT, 'TRANSLATIONAL VELOCITY'	00002310
WRITE (3,500) (FORCE(I), I = 4, 6)	00002320
DO 80 I = 1, 3	00002330
80 XHOLD(I) = XHOLD(I) + FORCE(I+3)	00002340
PRINT, 'TOTAL VELOCITY VECTOR'	00002350
WRITE (3,500) XHOLD	00002360
	00002370
PROJECT VELOCITY VECTOR ONTO TANGENT PLANE	00002380
	00002390
CALL VECTOR (TEMP, XHOLD, THOLD)	00002400
PRINT, 'UNIT VECTOR OF VELOCITY PROJECTED ONTO TANGENT PLANE'	00002410
WRITE (3,500) THOLD	00002420
	00002430
MULTIPLY NEG. UNIT VECTOR BY FRICTION SCALAR TO GET FRICTION VECTOR	00002440
	00002450
DO 90 I = 1, 3	00002460
90 WORK(I+3) = -THOLD(I) * PANEL(JS3)	00002470
	00002480
CREATE TOTAL FORCE VECTOR IN INERTIAL COORDINATES	00002490
	00002500

95 DO 100 I = 1, 3	00002510
100 TEMP(I) = WORK(I) + WORK(I+3)	00002520
16 PRINT, 'TOTAL FORCE VECTOR IN INERTIAL COORDINATES'	00002530
16 WRITE (3,500) TEMP	00002540
TRANSFORM TOTAL FORCE VECTOR TO SEGMENT Z-AXIAL COORDINATES.	00002550
CALL ROT2 (TEMP, 1, 3, 1)	00002560
15 PRINT, 'AFTER CHANGING TO X-AXIAL COORDINATES'	00002570
15 WRITE (3,500) TEMP	00002580
15 PRINT, ' '	00002590
CONVERT SEGMENT Z-AXIAL COORDINATES TO X-AXIAL.	00002600
XYZ(JXYZ+3) = TEMP(3)	00002610
XYZ(JXYZ+4) = TEMP(1)	00002620
XYZ(JXYZ+5) = TEMP(2)	00002630
120 CONTINUE	00002640
-----	00002650
JOINT FORCES & TORQUES; LINEAR & ANGULAR ACCELERATIONS	00002660
-----	00002670
IN BOTH INERTIAL AND LOCAL COORDINATES	00002680
LOCAL : ANGULAR VELOCITIES, ACCELERATIONS, U2 ARRAY	00002690
INERTIAL : JOINT FORCES & TORQUES, LINEAR ACCEL., U1 ARRAY	00002700
130 KT = KS + KP	00002710
KT6 = KT * 6	00002720
TRANSFORM INERTIAL VECTORS TO SEGMENT X-AXIAL LOCAL VECTORS.	00002730
14 PRINT, 'W, FORCES, TORQUES, ALPHA, ACCEL., U1, U2 IN ORIG. COORDS'	00002740
14 WRITE (3,600) (FORCE(I), I=10,30)	00002750
DO 134 J = 13, 25, 3	00002760
IF (J.EQ. 19) GO TO 134	00002770
CALL ROT (FORCE, J, 30, RAD, +1)	00002780
CALL CHANGE (FORCE, J, 30, 0.0)	00002790
134 CONTINUE	00002800
ROTATE LOCAL VECTORS TO X-AXIAL	00002810
DO 136 J = 10, 28, 9	00002820
136 CALL CHANGE (FORCE, J, 30, 0.0)	00002830
14 PRINT, 'SAME ITEMS IN SEGMENT X-AXIAL COORDINATES'	00002840
14 WRITE (3,600) (FORCE(J), J = 10, 30)	00002850
IF (YES(LIMB)) 140, 140, 138	00002860
TRANSFORM "OTHER CONSTRAINT FORCE" TO SEGMENT LOCAL X-AXIAL	00002870
138 CALL ROT (CNSTRN, 1, 6, RAD, +1)	00002880
CALL CHANGE (CNSTRN, 1, 6, 0.0)	00002890
	00002900
	00002910
	00002920
	00002930
	00002940
	00002950
	00002960
	00002970
	00002980
	00002990
	00003000

140 KS = YES(LIMB)	00003010
IF (KT .LT. 1 .AND. KS .LT. 1) GO TO 150	00003020
	00003030
CORRECT U1 & U2 ARRAYS TO ALLOW FOR POINT FORCE APPLICATIONS.	00003040
	00003050
DO 142 I = 1, 3	00003060
142 XHOLD(I) = 0.0	00003070
IF (KS .LT. 1) GO TO 144	00003080
	00003090
SUM TORQUES ABOUT C.G. DUE TO OTHER CONSTRAINT FORCES.	00003100
	00003110
XHOLD(1) = POSIT(KS+1) * CNSTRN(3) - POSIT(KS+2) * CNSTRN(2)	00003120
XHOLD(2) = -(POSIT(KS)-D1(LIMB)) * CNSTRN(3) + POSIT(KS+2) * CNSTRN(1)	00003130
XHOLD(3) = (POSIT(KS)-D1(LIMB)) * CNSTRN(2) - POSIT(KS+1) * CNSTRN(1)	00003140
IF (KT .LE. 1) GO TO 146	00003150
	00003160
SUM TORQUES ABOUT C.G. DUE TO CONTACT FORCES.	00003170
	00003180
144 GMASS = GINCH / WEIGHT(LIMB)	00003190
DO 145 J = 1, KT	00003200
I = 6 * J - 5	00003210
XHOLD(1) = XHOLD(1) + XYZ(I+1) * XYZ(I+5)	00003220
\$ - XYZ(I+2) * XYZ(I+4)	00003230
XHOLD(2) = XHOLD(2) - (XYZ(I)-D1(LIMB)) * XYZ(I+5)	00003240
\$ + XYZ(I+2) * XYZ(I+3)	00003250
XHOLD(3) = XHOLD(3) + (XYZ(I)-D1(LIMB)) * XYZ(I+4)	00003260
\$ - XYZ(I+1) * XYZ(I+3)	00003270
DO 145 JJ = 3, 5	00003280
FORCE(JJ+22) = FORCE(JJ+22) - GMASS * XYZ(I+JJ)	00003290
145 CONTINUE	00003300
146 CONTINUE	00003310
8 PRINT, 'U2 ARRAY IN X-AXIAL COORDINATES'	00003320
8 WRITE (3,500) (FORCE(J), J = 28,30)	00003330
8 PRINT, 'TORQUES DUE TO ALL POINT SEGMENT FORCES ABOUT C.G.'	00003340
8 WRITE(3,500) XHOLD	00003350
	00003360
ADD T/I TO U2 TO PRODUCE ADJUSTED ACCELERATION.	00003370
	00003380
DO 148 J = 1, 3	00003390
148 FORCE(J+27) = FORCE(J+27) + XHOLD(J) / INERT(J+LIMB0)	00003400
8 PRINT, 'ADJUSTED U2'	00003410
8 WRITE (3,500) (FORCE(J), J = 28,30)	00003420
	00003430
COMBINE A AND U1 INTO LOCATION OF A.	00003440
	00003450
150 DO 152 J = 22, 24	00003460
152 FORCE(J) = FORCE(J) - FORCE(J+3) / GINCH	00003470
	00003480
ORDER CONTACTS BY INCREASING X VALUE OF CONTACTING POINT	00003490
	00003500

IF (KT .LE. 1) GO TO 200	00003510
K = KT - 1	00003520
DO 170 I = 1, KT	00003530
J1 = 6 * I - 5	00003540
HOLD = XYZ(J1)	00003550
I1 = I + 1	00003560
NUM = J1	00003570
DO 158 J = I1, KT	00003580
J2 = 6 * J - 5	00003590
IF (XYZ(J2) .GE. HOLD) GO TO 158	00003600
NUM = J2	00003610
HOLD = XYZ(J2)	00003620
158 CONTINUE	00003630
IF (NUM .EQ. J1) GO TO 170	00003640
J1 = J1 - 1	00003650
NUM = NUM - 1	00003660
DO 160 K = 1, 6	00003670
J3 = 6 * K - 5	00003680
HOLD = XYZ(J1+K)	00003690
XYZ(J1+K) = XYZ(NUM+K)	00003700
160 XYZ(NUM+K) = HOLD	00003710
170 CONTINUE	00003720
200 IF (KT) 205, 205, 210	00003730
205 KT = 1	00003740
XYZ(1) = 0.0	00003750
GO TO 300	00003760
210 KT = KT * 6	00003770
300 CONTINUE	00003780
34 PRINT, 'CONTACT FORCES'	00003790
34 PRINT, 'NUMBER OF DATA ITEMS =', KT	00003800
34 K2 = KT / 6	00003810
34 IF (KT .GT. 1) WRITE (3,600) (XYZ(I), I = 1, KT)	00003820
	00003830
OUTPUT RESULTS TO DISK	00003840
	00003850
WRITE (9) LIMB,KT,NCON,(FORCE(I),I = 10,24),(FORCE(I),I = 28,30),	00003860
\$ (XYZ(I),I = 1, KT), (CNSTRN(I), I = 1, NCON)	00003870
350 CONTINUE	00003880
STOP	00003890
500 FORMAT(1H ,3F10.4)	00003900
600 FORMAT(1H ,3F10.4, ' --- ',3F10.4)	00003910
END	00003920
SUBROUTINE ROT (V, IZ, N, P, K)	00003930
	00003940
SUBROUTINE TO TRANSFORM VECTOR V THROUGH P RADIANS INTO ANOTHER	00003950
COORDINATE SYSTEM. K DETERMINES WHETHER THE TRANSFORMATION IS FROM	00003960
INERTIAL TO SEGMENT OR VICE-VERSA :	00003970
K = 1 INERTIAL TO SEGMENT TRANSFORMATION	00003980
K = -1 SEGMENT TO INERTIAL	00003990
	00004000

REAL R(3,3), V(N), VN(3), P(3)	00004010
COMMON /TRANS/ ICHEK	00004020
IF (ICHEK .EQ. 1) GO TO 10	00004030
ICHEK = 1	00004040
C1 = COS (P(1))	00004050
C2 = COS (P(2))	00004060
C3 = COS (P(3))	00004070
S1 = SIN (P(1))	00004080
S2 = SIN (P(2))	00004090
S3 = SIN (P(3))	00004100
R(1,1) = C2 * C1	00004110
R(2,1) = S3 * S2 * C1 - S1 * C3	00004120
R(3,1) = C3 * S2 * C1 + S1 * S3	00004130
R(1,2) = C2 * S1	00004140
R(2,2) = S3 * S2 * S1 + C1 * C3	00004150
R(3,2) = C3 * S2 * S1 - C1 * S3	00004160
R(1,3) = -S2	00004170
R(2,3) = S3 * C2	00004180
R(3,3) = C3 * C2	00004190
ENTRY ROT2 (V, IZ, N, K)	00004200
10 IZ1 = IZ - 1	00004210
IF (K) 40, 60, 20	00004220
20 DO 30 I = 1, 3	00004230
VN(I) = 0.0	00004240
DO 30 J = 1, 3	00004250
30 VN(I) = VN(I) + R(I,J) * V(IZ1+J)	00004260
GO TO 60	00004270
40 DO 50 I = 1, 3	00004280
VN(I) = 0.0	00004290
DO 50 J = 1, 3	00004300
50 VN(I) = VN(I) + R(J,I) * V(J)	00004310
60 DO 70 I = 1, 3	00004320
70 V(IZ1+I) = VN(I)	00004330
RETURN	00004340
END	00004350
SUBROUTINE VECTOR (N, V, C)	00004360
2	00004370
2 SUBROUTINE TO FIND THE VECTOR PROJECTION OF VECTOR V ONTO THE	00004380
2 PLANE WHICH N IS NORMAL TO. THE CROSS PRODUCT IS TAKEN TWICE	00004390
2 AND THE RESULTANT VECTOR IS NORMALIZED TO A UNIT VECTOR.	00004400
2	00004410
REAL N(3), V(3), C(3), D(3), HOLD	00004420
HOLD = 0.0	00004430
CALL CROSS (N, V, C)	00004440
CALL CROSS (C, N, D)	00004450
DO 10 J = 1, 3	00004460
10 HOLD = HOLD + D(J) * D(J)	00004470
HOLD = SQRT (HOLD)	00004480
IF (HOLD .EQ. 0.0) RETURN	00004490
DO 20 J = 1, 3	00004500

20	C(J) = D(J) / HOLD	00004510
	RETURN	00004520
	END	00004530
	SUBROUTINE CROSS (A, B, C)	00004540
		00004550
	SUBROUTINE TO TAKE THE CROSS PRODUCT OF A CROSS B, AND RETURN	00004560
	IT IN VECTOR C. A ,B AND C ARE ALL VECTORS OF LENGTH 3.	00004570
		00004580
	REAL A(3), B(3), C(3)	00004590
	C(1) = A(2) * B(3) - A(3) * B(2)	00004600
	C(2) = -A(1) * B(3) + A(3) * B(1)	00004610
	C(3) = A(1) * B(2) - A(2) * B(1)	00004620
	RETURN	00004630
	END	00004640
	SUBROUTINE CHANGE (TEMP, I, N, D)	00004650
		00004660
	CHANGES Z-AXIAL TO X-AXIAL COORDINATES. SHIFTS NEW X BY	00004670
	D TO ALLOW TRANSFER OF OFIGIN TO PROXIMAL JOINT.	00004680
		00004690
	REAL TEMP(N)	00004700
	HOLD1 = TEMP(I)	00004710
	HOLD2 = TEMP(I+1)	00004720
	HOLD3 = TEMP(I+2)	00004730
	TEMP(I) = HOLD3 + D	00004740
	TEMP(I+1) = HOLD1	00004750
	TEMP(I+2) = HOLD2	00004760
	RETURN	00004770
	END	00004780
	SUBROUTINE FOR (K)	00004790
	DO 10 J = 1, K	00004800
10	READ (5)	00004810
	RETURN	00004820
	END	00004830
	SUBROUTINE BACK (K)	00004840
	DO 10 J = 1, K	00004850
10	BACKSPACE 5	00004860
	RETURN	00004870
	END	00004880

FINDS AREA OF BONE AT VARIOUS LENGTHS	00000010
INTEGER TITLE(19)	00000020
REAL A(40), D(40), DNORM(40), X(40), Y(40), Z(40), U, JP	00000030
READ (1,100) TITLE	00000040
WRITE (3,150) TITLE	00000050
PRINT, 'NORM LENGTH, LENGTH, AREA'	00000060
PFINT, ' '	00000070
K = 1	00000080
10 READ (1,*,END=20) D(K), A(K)	00000090
K = K + 1	00000100
GO TO 10	00000110
20 K = K - 1	00000120
DO 30 I = 1, K	00000130
DNORM(I) = D(I) / D(K)	00000140
30 WRITE (3,200) DNORM(I), D(I), A(I)	00000150
CALL SPLINE (K, DNORM, A, X, Y, Z)	00000160
EVALUATE @ 11 POINTS NORMALIZED	00000170
PRINT, ' '	00000180
PRINT, ' '	00000190
PRINT, 'NORM LENGTH & AREA EVALUATED BY SEVAL'	00000200
PRINT, ' '	00000210
DO 40 I = 1, 11	00000220
U = FLOAT(I-1) / 10.0	00000230
TEMP = SEVAL (K, U, DNORM, A, X, Y, Z)	00000240
40 WRITE (3,200) U, TEMP	00000250
STOP	00000260
100 FORMAT (18A4)	00000270
150 FORMAT (' ID = ', 18A4)	00000280
200 FORMAT (3F10.3)	00000290
END	00000300
SUBROUTINE SPLINE (N, X, Y, B, C, D)	00000310
INTEGER N	00000320
REAL X(N), Y(N), B(N), C(N), D(N)	00000330
INTEGER NM1, IB, I	00000340
REAL T	00000350
NM1 = N-1	00000360
IF (N .LT. 2) RETURN	00000370
IF (N .LT. 3) GO TO 50	00000380
D(1) = X(2) - X(1)	00000390
C(2) = (Y(2) - Y(1))/D(1)	00000400
DO 10 I = 2, NM1	00000410
D(I) = X(I+1) - X(I)	00000420
B(I) = 2.*(D(I-1) + D(I))	00000430
C(I+1) = (Y(I+1) - Y(I))/D(I)	00000440
C(I) = C(I+1) - C(I)	00000450
10 CONTINUE	00000460
B(1) = -D(1)	00000470
B(N) = -D(N-1)	00000480
	00000490
	00000500

C(1) = 0.	00000510
C(N) = 0.	00000520
IF (N .EQ. 3) GO TO 15	00000530
C(1) = C(3)/(X(4)-X(2)) - C(2)/(X(3)-X(1))	00000540
C(N) = C(N-1)/(X(N)-X(N-2)) - C(N-2)/(X(N-1)-X(N-3))	00000550
C(1) = C(1)*D(1)**2/(X(4)-X(1))	00000560
C(N) = -C(N)*D(N-1)**2/(X(N)-X(N-3))	00000570
15 DO 20 I = 2, N	00000580
T = D(I-1)/B(I-1)	00000590
B(I) = B(I) - T*D(I-1)	00000600
C(I) = C(I) - T*C(I-1)	00000610
20 CONTINUE	00000620
C(N) = C(N)/B(N)	00000630
DO 30 IB = 1, NM1	00000640
I = N-IB	00000650
C(I) = (C(I) - D(I)*C(I+1))/B(I)	00000660
30 CONTINUE	00000670
B(N) = (Y(N) - Y(NM1))/D(NM1) + D(NM1)*(C(NM1) + 2.*C(N))	00000680
DO 40 I = 1, NM1	00000690
B(I) = (Y(I+1) - Y(I))/D(I) - D(I)*(C(I+1) + 2.*C(I))	00000700
D(I) = (C(I+1) - C(I))/D(I)	00000710
C(I) = 3.*C(I)	00000720
40 CONTINUE	00000730
C(N) = 3.*C(N)	00000740
D(N) = D(N-1)	00000750
RETURN	00000760
50 B(1) = (Y(2)-Y(1))/(X(2)-X(1))	00000770
C(1) = 0.	00000780
D(1) = 0.	00000790
B(2) = B(1)	00000800
C(2) = 0.	00000810
D(2) = 0.	00000820
RETURN	00000830
END	00000840
REAL FUNCTION SEVAL(N, U, X, Y, B, C, D)	00000850
INTEGER N	00000860
REAL U, X(N), Y(N), B(N), C(N), D(N)	00000870
INTEGER I, J, K	00000880
REAL DX	00000890
DATA I/1/	00000900
IF (I .GE. N) I = 1	00000910
IF (U .LT. X(I)) GO TO 10	00000920
IF (U .LE. X(I+1)) GO TO 30	00000930
10 I = 1	00000940
J = N+1	00000950
20 K = (I+J)/2	00000960
IF (U .LT. X(K)) J = K	00000970
IF (U .GE. X(K)) I = K	00000980
IF (J .GT. I+1) GO TO 20	00000990
30 DX = U - X(I)	00001000

```

SEVAL = Y(I) + DX*(B(I) + DX*(C(I) + DX*D(I)))
RETURN
END

```

```

00001010
00001020
00001030
00001040
00001050
00001060
00001070
00001080
00001090
00001100
00001110
00001120
00001130
00001140
00001150
00001160
00001170
00001180
00001190
00001200

```

```

SDATA
FEMUR #1 -- RIGHT    DISTAL VS. AVG. INERTIA
1.0      .226
2.0      .092
3.0      .076
4.0      .075
5.0      .074
6.0      .069
7.2      .067
8.2      .065
9.2      .066
10.2     .067
11.2     .073
12.2     .085
13.2     .105
14.2     .249
14.2     1.818

```


DOUBLE PRECISION FUNCTION ZEROIN(AX,BX,F,TOL)
DOUBLE PRECISION AX,BX,F,TOL

A ZERO OF THE FUNCTION F(X) IS COMPUTED IN THE INTERVAL AX,BX .

INPUT..

AX LEFT ENDPOINT OF INITIAL INTERVAL
BX RIGHT ENDPOINT OF INITIAL INTERVAL
F FUNCTION SUBPROGRAM WHICH EVALUATES F(X) FOR ANY X IN
THE INTERVAL AX,BX
TOL DESIRED LENGTH OF THE INTERVAL OF UNCERTAINTY OF THE
FINAL RESULT (.GE. 0.0D0)

OUTPUT..

ZEROIN ABCISSA APPROXIMATING A ZERO OF F IN THE INTERVAL AX,BX

IT IS ASSUMED THAT F(AX) AND F(BX) HAVE OPPOSITE SIGNS
WITHOUT A CHECK. ZEROIN RETURNS A ZERO X IN THE GIVEN INTERVAL
AX,BX TO WITHIN A TOLERANCE $4 * \text{MACHEPS} * \text{ABS}(X) + \text{TOL}$, WHERE MACHEPS
IS THE RELATIVE MACHINE PRECISION.

THIS FUNCTION SUBPROGRAM IS A SLIGHTLY MODIFIED TRANSLATION OF
THE ALGOL 60 PROCEDURE ZERO GIVEN IN RICHARD BRENT, ALGORITHMS FOR
MINIMIZATION WITHOUT DERIVATIVES, PRENTICE - HALL, INC. (1973).

DOUBLE PRECISION A,B,C,D,E,EPS,FA,FB,FC,TOL1,XM,P,Q,R,S
DOUBLE PRECISION DABS,DSIGN

COMPUTE EPS, THE RELATIVE MACHINE PRECISION

EPS = 1.0D0
10 EPS = EPS/2.0D0
TOL1 = 1.0D0 + EPS
IF (TOL1 .GT. 1.0D0) GO TO 10

INITIALIZATION

A = AX
B = BX
FA = F(A)
FB = F(B)

BEGIN STEP

20 C = A
FC = FA

```

D = B - A
E = D
30 IF (DABS(FC) .GE. DABS(FB)) GO TO 40
A = B
B = C
C = A
FA = FB
FB = FC
FC = FA
:
: CONVERGENCE TEST
:
40 TOL1 = 2.0D0*EPS*DABS(B) + 0.5D0*TOL
XM = .5*(C - B)
IF (DABS(XM) .LE. TOL1) GO TO 90
IF (FB .EQ. 0.0D0) GO TO 90
:
: IS BISECTION NECESSARY
:
IF (DABS(E) .LT. TOL1) GO TO 70
IF (DABS(FA) .LE. DABS(FB)) GO TO 70
:
: IS QUADRATIC INTERPOLATION POSSIBLE
:
IF (A .NE. C) GO TO 50
:
: LINEAR INTERPOLATION
:
S = FB/FA
P = 2.0D0*XM*S
Q = 1.0D0 - S
GO TO 60
:
: INVERSE QUADRATIC INTERPOLATION
:
50 Q = FA/PC
R = FB/FC
S = FB/FA
P = S*(2.0D0*XM*Q*(Q - R) - (B - A)*(R - 1.0D0))
Q = (Q - 1.0D0)*(R - 1.0D0)*(S - 1.0D0)
:
: ADJUST SIGNS
:
60 IF (P .GT. 0.0D0) Q = -Q
P = DABS(P)
:
: IS INTERPOLATION ACCEPTABLE
:
IF ((2.0D0*P) .GE. (3.0D0*XM*Q - DABS(TOL1*Q))) GO TO 70
IF (P .GE. DABS(0.5D0*E*Q)) GO TO 70

```

E = D
D = P/Q
GO TO 80

:
: BISECTION
:

70 D = XM
E = D

:
: COMPLETE STEP
:

80 A = B
FA = FB
IF (DABS(D) .GT. TOL1) B = B + D
IF (DABS(D) .LE. TOL1) B = B + DSIGN(TOL1, XM)
FB = F(B)
IF ((FB*(FC/DABS(FC))) .GT. 0.0D0) GO TO 20
GO TO 30

:
: DONE
:

90 ZEROIN = B
RETURN
END

SUBROUTINE SPLINE (N, X, Y, B, C, D)

INTEGER N

DOUBLE PRECISION X(N), Y(N), B(N), C(N), D(N)

THE COEFFICIENTS B(I), C(I), AND D(I), I=1,2,...,N ARE COMPUTED
FOR A CUBIC INTERPOLATING SPLINE

$S(X) = Y(I) + B(I)*(X-X(I)) + C(I)*(X-X(I))^{**2} + D(I)*(X-X(I))^{**3}$

FOR $X(I) \leq X \leq X(I+1)$

INPUT..

N = THE NUMBER OF DATA POINTS OR KNOTS (N.GE.2)

X = THE ABSCISSAS OF THE KNOTS IN STRICTLY INCREASING ORDER

Y = THE ORDINATES OF THE KNOTS

OUTPUT..

B, C, D = ARRAYS OF SPLINE COEFFICIENTS AS DEFINED ABOVE.

USING P TO DENOTE DIFFERENTIATION,

$Y(I) = S(X(I))$

$B(I) = SP(X(I))$

$C(I) = SPP(X(I))/2$

$D(I) = SPPP(X(I))/6$ (DERIVATIVE FROM THE RIGHT)

THE ACCOMPANYING FUNCTION SUBPROGRAM SEVAL CAN BE USED
TO EVALUATE THE SPLINE.

INTEGER NM1, IB, I

DOUBLE PRECISION T

NM1 = N-1

IF (N .LT. 2) RETURN

IF (N .LT. 3) GO TO 50

SET UP TRIDIAGONAL SYSTEM

B = DIAGONAL, D = OFFDIAGONAL, C = RIGHT HAND SIDE.

$D(1) = X(2) - X(1)$

$C(2) = (Y(2) - Y(1))/D(1)$

DO 10 I = 2, NM1

$D(I) = X(I+1) - X(I)$

$B(I) = 2.*(D(I-1) + D(I))$

$C(I+1) = (Y(I+1) - Y(I))/D(I)$

$C(I) = C(I+1) - C(I)$

10 CONTINUE

END CONDITIONS. THIRD DERIVATIVES AT X(1) AND X(N)
OBTAINED FROM DIVIDED DIFFERENCES

B(1) = -D(1)
B(N) = -D(N-1)
C(1) = 0.
C(N) = 0.
IF (N .EQ. 3) GO TO 15
C(1) = C(3)/(X(4)-X(2)) - C(2)/(X(3)-X(1))
C(N) = C(N-1)/(X(N)-X(N-2)) - C(N-2)/(X(N-1)-X(N-3))
C(1) = C(1)*D(1)**2/(X(4)-X(1))
C(N) = -C(N)*D(N-1)**2/(X(N)-X(N-3))

FORWARD ELIMINATION

15 DO 20 I = 2, N
T = D(I-1)/B(I-1)
B(I) = B(I) - T*D(I-1)
C(I) = C(I) - T*C(I-1)
20 CONTINUE

BACK SUBSTITUTION

C(N) = C(N)/B(N)
DO 30 IB = 1, NM1
I = N-IB
C(I) = (C(I) - D(I)*C(I+1))/B(I)
30 CONTINUE

C(I) IS NOW THE SIGMA(I) OF THE TEXT

COMPUTE POLYNOMIAL COEFFICIENTS

B(N) = (Y(N) - Y(NM1))/D(NM1) + D(NM1)*(C(NM1) + 2.*C(N))
DO 40 I = 1, NM1
B(I) = (Y(I+1) - Y(I))/D(I) - D(I)*(C(I+1) + 2.*C(I))
D(I) = (C(I+1) - C(I))/D(I)
C(I) = 3.*C(I)
40 CONTINUE
C(N) = 3.*C(N)
D(N) = D(N-1)
RETURN

50 B(1) = (Y(2)-Y(1))/(X(2)-X(1))
C(1) = 0.
D(1) = 0.
B(2) = B(1)
C(2) = 0.

D(2) = 0.
RETURN
END

DOUBLE PRECISION FUNCTION SEVAL(N, U, X, Y, B, C, D)

INTEGER N

DOUBLE PRECISION U, X(N), Y(N), B(N), C(N), D(N)

THIS SUBROUTINE EVALUATES THE CUBIC SPLINE FUNCTION

SEVAL = Y(I) + B(I)*(U-X(I)) + C(I)*(U-X(I))**2 + D(I)*(U-X(I))**3

WHERE X(I) .LT. U .LT. X(I+1), USING HORNER'S RULE

IF U .LT. X(1) THEN I = 1 IS USED.

IF U .GE. X(N) THEN I = N IS USED.

INPUT..

N = THE NUMBER OF DATA POINTS

U = THE ABSCISSA AT WHICH THE SPLINE IS TO BE EVALUATED

X,Y = THE ARRAYS OF DATA ABSCISSAS AND ORDINATES

B,C,D = ARRAYS OF SPLINE COEFFICIENTS COMPUTED BY SPLINE

IF U IS NOT IN THE SAME INTERVAL AS THE PREVIOUS CALL, THEN A
BINARY SEARCH IS PERFORMED TO DETERMINE THE PROPER INTERVAL.

INTEGER I, J, K

DOUBLE PRECISION DX

DATA I/1/

IF (I .GE. N) I = 1

IF (U .LT. X(I)) GO TO 10

IF (U .LE. X(I+1)) GO TO 30

BINARY SEARCH

10 I = 1

J = N+1

20 K = (I+J)/2

IF (U .LT. X(K)) J = K

IF (U .GE. X(K)) I = K

IF (J .GT. I+1) GO TO 20

EVALUATE SPLINE

30 DX = U - X(I)

SEVAL = Y(I) + DX*(B(I) + DX*(C(I) + DX*D(I)))

RETURN

END

```

DOUBLE PRECISION FUNCTION FMIN(AX,BX,F,TOL)
DOUBLE PRECISION AX,BX,F,TOL

```

AN APPROXIMATION X TO THE POINT WHERE F ATTAINS A MINIMUM ON THE INTERVAL (AX,BX) IS DETERMINED.

INPUT..

```

AX      LEFT ENDPOINT OF INITIAL INTERVAL
BX      RIGHT ENDPOINT OF INITIAL INTERVAL
F       FUNCTION SUBPROGRAM WHICH EVALUATES F(X) FOR ANY X
        IN THE INTERVAL (AX,BX)
TOL     DESIRED LENGTH OF THE INTERVAL OF UNCERTAINTY OF THE FINAL
        RESULT ( .GE. 0.0D0)

```

OUTPUT..

FMIN ABCISSA APPROXIMATING THE POINT WHERE F ATTAINS A MINIMUM

THE METHOD USED IS A COMBINATION OF GOLDEN SECTION SEARCH AND SUCCESSIVE PARABOLIC INTERPOLATION. CONVERGENCE IS NEVER MUCH SLOWER THAN THAT FOR A FIBONACCI SEARCH. IF F HAS A CONTINUOUS SECOND DERIVATIVE WHICH IS POSITIVE AT THE MINIMUM (WHICH IS NOT AT AX OR BX), THEN CONVERGENCE IS SUPERLINEAR, AND USUALLY OF THE ORDER OF ABOUT 1.324....

THE FUNCTION F IS NEVER EVALUATED AT TWO POINTS CLOSER TOGETHER THAN $\text{EPS} \cdot \text{ABS}(\text{FMIN}) + (\text{TOL}/3)$, WHERE EPS IS APPROXIMATELY THE SQUARE ROOT OF THE RELATIVE MACHINE PRECISION. IF F IS A UNIMODAL FUNCTION AND THE COMPUTED VALUES OF F ARE ALWAYS UNIMODAL WHEN SEPARATED BY AT LEAST $\text{EPS} \cdot \text{ABS}(X) + (\text{TOL}/3)$, THEN FMIN APPROXIMATES THE ABCISSA OF THE GLOBAL MINIMUM OF F ON THE INTERVAL AX,BX WITH AN ERROR LESS THAN $3 \cdot \text{EPS} \cdot \text{ABS}(\text{FMIN}) + \text{TOL}$. IF F IS NOT UNIMODAL, THEN FMIN MAY APPROXIMATE A LOCAL, BUT PERHAPS NON-GLOBAL, MINIMUM TO THE SAME ACCURACY.

THIS FUNCTION SUBPROGRAM IS A SLIGHTLY MODIFIED VERSION OF THE ALGOL 60 PROCEDURE LOCALMIN GIVEN IN RICHARD BRENT, ALGORITHMS FOR MINIMIZATION WITHOUT DERIVATIVES, PRENTICE - HALL, INC. (1973).

```

DOUBLE PRECISION A,B,C,D,E,EPS,XN,P,Q,R,TOL1,TOL2,U,V,W
DOUBLE PRECISION FU,FV,FW,FX,X
DOUBLE PRECISION DABS,DSQRT,DSIGN

```

C IS THE SQUARED INVERSE OF THE GOLDEN RATIO

$C = 0.5D0 \cdot (3. - \text{DSQRT}(5.0D0))$

: EPS IS APPROXIMATELY THE SQUARE ROOT OF THE RELATIVE MACHINE
: PRECISION.

:
: EPS = 1.0D00
10 EPS = EPS/2.0D00
: TOL1 = 1.0D0 + EPS
: IF (TOL1 .GT. 1.0D00) GO TO 10
: EPS = DSQRT(EPS)

:
: INITIALIZATION

:
: A = AX
: B = BY
: V = A + C*(B - A)
: W = V
: X = V
: E = 0.0D0
: FX = F(X)
: FV = FX
: FW = FX

:
: MAIN LOOP STARTS HERE

:
20 XM = 0.5D0*(A + B)
: TOL1 = EPS*DABS(X) + TOL/3.0D0
: TOL2 = 2.0D0*TOL1

:
: CHECK STOPPING CRITERION

: IF (DABS(X - XM) .LE. (TOL2 - 0.5D0*(B - A))) GO TO 90

:
: IS GOLDEN-SECTION NECESSARY

: IF (DABS(E) .LE. TOL1) GO TO 40

:
: FIT PARABOLA

:
: R = (X - W)*(FX - FV)
: Q = (X - V)*(FX - FW)
: P = (X - V)*Q - (X - W)*R
: Q = 2.0D00*(Q - R)
: IF (Q .GT. 0.0D0) P = -P
: Q = DABS(Q)
: R = E
: E = D

:
: IS PARABOLA ACCEPTABLE

:
30 IF (DABS(P) .GE. DABS(0.5D0*Q*R)) GO TO 40
: IF (P .LE. Q*(A - X)) GO TO 40

IF (P .GE. Q*(B - X)) GO TO 40

A PARABOLIC INTERPOLATION STEP

D = P/Q
U = X + D

F MUST NOT BE EVALUATED TOO CLOSE TO AX OR BX

IF (U - A) .LT. TOL2) D = DSIGN(TOL1, XM - X)
IF (B - U) .LT. TOL2) D = DSIGN(TOL1, XM - X)
GO TO 50

A GOLDEN-SECTION STEP

40 IF (X .GE. XM) E = A - X
IF (X .LT. XM) E = B - X
D = C*E

F MUST NOT BE EVALUATED TOO CLOSE TO X

50 IF (DABS(D) .GE. TOL1) U = X + D
IF (DABS(D) .LT. TOL1) U = X + DSIGN(TOL1, D)
FU = F(U)

UPDATE A, B, V, W, AND X

IF (FU .GT. FX) GO TO 60
IF (U .GE. X) A = X
IF (U .LT. X) B = X
V = W
FV = FW
W = X
FW = FX
X = U
PX = FU
GO TO 20

60 IF (U .LT. X) A = U
IF (U .GE. X) B = U
IF (FU .LE. FW) GO TO 70
IF (W .EQ. X) GO TO 70
IF (FU .LE. FV) GO TO 80
IF (V .EQ. X) GO TO 80
IF (V .EQ. W) GO TO 80
GO TO 20

70 V = W
FV = FW
W = U
FW = FU
GO TO 20

80 V = U
PV = PU
GO TO 20

END OF MAIN LOOP

90 PHIN = X
RETURN
END

```

*****
PROGRAM NAME : MAPGRAF
WRITTEN BY : J.F. BRANDEAU
COMPILER(S) : WATFIV (DOUBLE PRECISION)
-----
PURPOSE : USE COEFFICIENTS X TO PRODUCE DATA POINTS THAT WILL BE READ
BY SAS TO PRODUCE A 3-D PLOT OF A STRESS-STRAIN SURFACE. PROGRAM
CREATES A GRID OF STRAIN VS. LOG STRAIN RATE, AND USES SUBROUTINE
ZEROIN TO SOLVE FOR THE VALUE OF STRESS FOR EACH UNIQUE COMBINATION.
THE DENSITY OF THE GRID, THE RANGE OF THE GRID, AND THE NON-
PERMISSIBLE REGION ARE ALL CONTROLLABLE. THE NON-PERMISSIBLE REGION
OF THE GRID WILL HAVE NO POINTS ON IT, TO PREVENT EXTRAPOLATION PAST
EXPERIMENTAL LIMITS. THE SHAPE OF THE EDGE IS CALCULATED USING A
SPLINE CURVE FIT TO THE MAX VALUES OF STRAIN FOR EACH OBSERVED STRESS
THIS IS DONE BY SUBROUTINE SPLINE AND SEVAL.
-----
VARIABLES :
A1 & B1 : A1 IS THE MAX OBSERVED VALUES OF STRAIN, ONE FOR EACH VALUE
OF STRAIN RATE B1. B1 MUST START WITH LOWEST VALUE OF STRAIN RATE
FIRST, OR THE SPLINE WILL BE INCORRECTLY CALCULATED.
K : THE NUMBER OF UNIQUE STRAIN RATES OBSERVED, ALSO THE NUMBER OF
ELEMENTS I EACH OF A1 & B1.
SIGMAX : GREATER THAN THE EXPECTED MAX VALUE OF STRESS (KSI) TO BE
USED AS THE UPPER LIMIT OF SEARCH FOR ZEROIN. FOR EACH UNIQUE
STRAIN RATE THIS MAY BE CORRECTED DOWNWARD BY THE PROGRAM TO PREVENT
OVERFLOWS. THIS IS SET BY THE USER.
A,B,N,D,C & COEFF : A,B,N,D, & C ARE THE MANTISSA OF THE COEFFICIENTS
FOR THE EQUATION, AND COEFF IS THE EXPONENTS. THE PRODUCTS
A * COEFF(1), B * COEFF(2), ETC... ARE THE COEFFICIENTS.
X1 : THE STARTING POINT FOR VALUES OF STRAIN. THIS MUST BE GREATER
THAN ZERO, AS THE EQUATION IS INDETERMINATE @ STRAIN = 0.0.
Y1 : THE STARTING POINT FOR LOG RATE. Y1 = -3 IS A STARTING POINT OF
STRAIN RATE = 0.001 / SEC.
DY : STEP LENGTH IN LOG RATE (OR Y) DIRECTION.
DX : " " " STRAIN (OR X) "
YMAX : MAX VALUE OF LOG RATE TO BE USED & IS ASSIGNED BY THE USER.
THOLD = MAX VALUE OF STRAIN TO USE, & IS SET BY PROGRAM TO EQUAL
MAX VALUE IN A1.

```

```

: TOL : CONVERGENCE CRITERIA FOR ZEROIN. *00000510
: IX : # OF POINTS ON STRAIN (X) AXIS. *00000520
: IY : " " " " LOG RATE (Y) " *00000530
: THE TOTAL GRID WILL CONSIST OF IY * IX - NON-PERMISSIBLE POINTS. *00000540
: C1,D1,E1 : WORK VECTORS FOR SPLINE & SEVAL. MUST NOT BE CHANGED. *00000550
: ----- *00000560
: I/O REQUIREMENTS : *00000570
: FILE #5 : MANTISSA OF COEFFICIENT VECTOR AND EXPONENT OF COEFFICIENT *00000580
: VECTOR ON TWO RECORDS. *00000590
: ----- *00000600
: OPTIONS : NONE *00000610
: ***** *00000620
: IMPLICIT REAL * 8 (A-H, N, O-Z) *00000630
: EXTERNAL FUNCT *00000640
: DIMENSION Y(40), X(40), YE(40), COEFF(5) *00000650
: DIMENSION A1(6), B1(6), C1(6), D1(6), E1(6) *00000660
: COMMON X, Y, I, J, A, B, C, D, N, RATEB, RATED, TLOG *00000670
: COMMON /SUB1/ GEPS *00000680
: DATA A1/6.90D-3, 6.5D-3, 5.7D-3, 5.1D-3, 10.5D-3, 9.2D-3/ *00000690
: DATA B1 /.001, 0.10, 10.0, 150.0, 0.0, 0.0/ *00000700
: SET PROGRAM PARAMETERS *00000710
: K = 4 *00000720
: YMAX = 2.3 *00000730
: SIGMAX = 25.0D0 *00000740
: X1 = 0.05D-3 ; Y1 = -3.0D0 *00000750
: TOL = 1.0D-8 ; IX = 30 ; IY = 30 *00000760
: THOLD = 0.0 *00000770
: DO 5 J = 1, K *00000780
: IF (A1(J) .GT. THOLD) THOLD = A1(J) *00000790
: 5 B1(J) = DLOG10 (B1(J)) *00000800
: CALL SPLINE (K, B1, A1, C1, D1, E1) *00000810
: READ (5,*) A, B, N, D, C *00000820
: READ (5,*) COEFF *00000830
: A = A * COEFF(1) ; B = B * COEFF(2) ; N = N * COEFF(3) *00000840
: D = D * COEFF(4) ; C = C * COEFF(5) *00000850
: PRINT, 'A ',A ; PRINT, 'B ',B ; PRINT, 'N ',N *00000860
: PRINT, 'D ',D ; PRINT, 'C ',C *00000870
: CHECK FOR VALUES THAT WILL CAUSE OVER/UNDER FLOW *00000880
: IF (A .EQ. 0.0D0) THEN DO *00000890
: TLOG = -80.0D0 *00000900
: *00000910
: *00000920
: *00000930
: *00000940
: *00000950
: *00000960
: *00000970
: *00000980
: *00000990
: *00001000

```

ELSE DO	00001010
TLOG = DLOG10 (A)	00001020
ENDIF	00001030
DX = (THOLD - X1) / DFLOAT (IX-1)	00001040
DY = (YMAX - Y1) / DFLOAT (IY-1)	00001050
DO 10 J = 1, IY	00001060
Y(J) = DFLOAT(J-1) * DY + Y1	00001070
10 YE(J) = 10.0 ** Y(J)	00001080
DO 20 I = 1, IX	00001090
20 X(I) = DFLOAT(I-1) * DX + X1	00001100
	00001110
	00001120
CALCULATE MACHINE EPSILON FOR ZEROIN	00001130
	00001140
GEPS = 1.0D0	00001150
24 GEPS = GEPS/2.0D0	00001160
TOL1 = 1.0D0 + GEPS	00001170
IF (TOL1 .GT. 1.0D0) GO TO 24	00001180
	00001190
BEGIN SOLUTIONS	00001200
	00001210
DO 40 J = 1, IY	00001220
	00001230
CORRECT BX IF NEEDED TO PREVENT OVERFLOW	00001240
	00001250
BX = SIGMAX	00001260
RATEB = DLOG10 (YE(J) ** B)	00001270
25 AX = N * DLOG10 (BX) + RATEB	00001280
IF (AX .GT. 75.0D0) THEN DO	00001290
BX = BX - 0.5D0	00001300
GO TO 25	00001310
ENDIF	00001320
	00001330
RATEB = YE(J) ** B	00001340
RATED = C * YE(J) ** D	00001350
Z = X(1) * RATED / 1.3	00001360
TEMP = SEVAL (K, Y(J), B1, A1, C1, D1, E1)	00001370
	00001380
ALLOW FOR SPLINE RIPPLE	00001390
IF (TEMP .GT. (THOLD * 0.97D0)) TEMP = THOLD	00001400
	00001410
DO 30 I = 1, IX	00001420
IF (X(I) .GT. TEMP) GO TO 40	00001430
AX = Z	00001440
Z = ZEROIN (AX, BX, FUNCT, TOL)	00001450
WRITE (6,400) X(I), Y(J), YE(J), Z	00001460
30 CONTINUE	00001470
40 CONTINUE	00001480
STOP	00001490
400 FORMAT (1H ,5(1PD13.5))	00001500

END	00001510
DOUBLE PRECISION FUNCTION FUNCT(STRESS)	00001520
IMPLICIT REAL * 8 (A-H, N, O-Z)	00001530
DIMENSION Y(40), X(40)	00001540
COMMON X, Y, I, J, A, B, C, D, N, RATEB, RATED, TLOG	00001550
T1 = STRESS / RATED	00001560
IF (STRESS .GT. 1.0D-1) GO TO 10	00001570
IF ((N * DLOG10(STRESS)) .GT. -60.0D0) GO TO 10	00001580
HOLD = -25.0D0	00001590
GO TO 15	00001600
10 T2 = STRESS ** N	00001610
HOLD = DLOG10 (T2)	00001620
15 IF ((HOLD + TLOG) .LT. -17.0D0) THEN DO	00001630
FUNCT = T1 - X(I)	00001640
ELSE DO	00001650
FUNCT = T1 + A * T2 * RATEB - X(I)	00001660
ENDIF	00001670
25 RETURN	00001680
END	00001690
ISOPTIONS NOLIST	00001700
DOUBLE PRECISION FUNCTION ZEROIN(AX,BX,F,TOL)	00001710
DOUBLE PRECISION AX,BX,F,TOL	00001720
DOUBLE PRECISION A,B,C,D,E,EPS,FA,FB,FC,TOL1,XM,P,Q,R,S	00001730
DOUBLE PRECISION DABS,DSIGN	00001740
COMMON /SUB1/ EPS	00001750
A = AX	00001760
B = BX	00001770
FA = F(A)	00001780
FB = F(B)	00001790
20 C = A	00001800
FC = FA	00001810
D = B - A	00001820
E = D	00001830
30 IF (DABS(FC) .GE. DABS(FB)) GO TO 40	00001840
A = B	00001850
B = C	00001860
C = A	00001870
FA = FB	00001880
FB = FC	00001890
FC = FA	00001900
40 TOL1 = 2.0D0*EPS*DABS(B) + 0.5D0*TOL	00001910
XM = .5*(C - B)	00001920
IF (DABS(XM) .LE. TOL1) GO TO 90	00001930
IF (FB .EQ. 0.0D0) GO TO 90	00001940
IF (DABS(E) .LT. TOL1) GO TO 70	00001950
IF (DABS(FA) .LE. DABS(FB)) GO TO 70	00001960
IF (A .NE. C) GO TO 50	00001970
S = FB/FA	00001980
P = 2.0D0*XM*S	00001990
Q = 1.0D0 - S	00002000

GO TO 60	00002010
50 Q = FA/FC	00002020
R = FB/FC	00002030
S = FB/FA	00002040
P = S*(2.0D0*XM*Q*(Q - R) - (B - A)*(R - 1.0D0))	00002050
Q = (Q - 1.0D0)*(R - 1.0D0)*(S - 1.0D0)	00002060
60 IF (P .GT. 0.0D0) Q = -Q	00002070
P = DABS(P)	00002080
IF ((2.0D0*P) .GE. (3.0D0*XM*Q - DABS(TOL1*Q))) GO TO 70	00002090
IF (P .GE. DABS(0.5D0*E*Q)) GO TO 70	00002100
E = D	00002110
D = P/Q	00002120
GO TO 80	00002130
70 D = XM	00002140
E = D	00002150
80 A = B	00002160
FA = FB	00002170
IF (DABS(D) .GT. TOL1) B = B + D	00002180
IF (DABS(D) .LE. TOL1) B = B + DSIGN(TOL1, XM)	00002190
FB = F(B)	00002200
IF ((FB*(FC/DABS(FC))) .GT. 0.0D0) GO TO 20	00002210
GO TO 30	00002220
90 ZEROIN = B	00002230
RETURN	00002240
END	00002250
SUBROUTINE SPLINE (N, X, Y, B, C, D)	00002260
INTEGER N	00002270
DOUBLE PRECISION X(N), Y(N), B(N), C(N), D(N)	00002280
INTEGER NM1, IB, I	00002290
DOUBLE PRECISION T	00002300
NM1 = N-1	00002310
IF (N .LT. 2) RETURN	00002320
IF (N .LT. 3) GO TO 50	00002330
D(1) = X(2) - X(1)	00002340
C(2) = (Y(2) - Y(1))/D(1)	00002350
DO 10 I = 2, NM1	00002360
D(I) = X(I+1) - X(I)	00002370
B(I) = 2.*(D(I-1) + D(I))	00002380
C(I+1) = (Y(I+1) - Y(I))/D(I)	00002390
C(I) = C(I+1) - C(I)	00002400
10 CONTINUE	00002410
B(1) = -D(1)	00002420
B(N) = -D(N-1)	00002430
C(1) = 0.	00002440
C(N) = 0.	00002450
IF (N .EQ. 3) GO TO 15	00002460
C(1) = C(3)/(X(4)-X(2)) - C(2)/(X(3)-X(1))	00002470
C(N) = C(N-1)/(X(N)-X(N-2)) - C(N-2)/(X(N-1)-X(N-3))	00002480
C(1) = C(1)*D(1)**2/(X(4)-X(1))	00002490
C(N) = -C(N)*D(N-1)**2/(X(N)-X(N-3))	00002500

15 DO 20 I = 2, N	00002510
T = D(I-1)/B(I-1)	00002520
B(I) = B(I) - T*D(I-1)	00002530
C(I) = C(I) - T*C(I-1)	00002540
20 CONTINUE	00002550
C(N) = C(N)/B(N)	00002560
DO 30 IB = 1, NM1	00002570
I = N-IB	00002580
C(I) = (C(I) - D(I)*C(I+1))/B(I)	00002590
30 CONTINUE	00002600
B(N) = (Y(N) - Y(NM1))/D(NM1) + D(NM1)*(C(NM1) + 2.*C(N))	00002610
DO 40 I = 1, NM1	00002620
B(I) = (Y(I+1) - Y(I))/D(I) - D(I)*(C(I+1) + 2.*C(I))	00002630
D(I) = (C(I+1) - C(I))/D(I)	00002640
C(I) = 3.*C(I)	00002650
40 CONTINUE	00002660
C(N) = 3.*C(N)	00002670
D(N) = D(N-1)	00002680
RETURN	00002690
50 B(1) = (Y(2)-Y(1))/(X(2)-X(1))	00002700
C(1) = 0.	00002710
D(1) = 0.	00002720
B(2) = B(1)	00002730
C(2) = 0.	00002740
D(2) = 0.	00002750
RETURN	00002760
END	00002770
DOUBLE PRECISION FUNCTION SEVAL(N, U, X, Y, B, C, D)	00002780
INTEGER N	00002790
DOUBLE PRECISION U, X(N), Y(N), B(N), C(N), D(N)	00002800
INTEGER I, J, K	00002810
DOUBLE PRECISION DX	00002820
DATA I/1/	00002830
IF (I .GE. N) I = 1	00002840
IF (U .LT. X(I)) GO TO 10	00002850
IF (U .LE. X(I+1)) GO TO 30	00002860
10 I = 1	00002870
J = N+1	00002880
20 K = (I+J)/2	00002890
IF (U .LT. X(K)) J = K	00002900
IF (U .GE. X(K)) I = K	00002910
IF (J .GT. I+1) GO TO 20	00002920
30 DX = U - X(I)	00002930
SEVAL = Y(I) + DX*(B(I) + DX*(C(I) + DX*D(I)))	00002940
RETURN	00002950
END	00002960

```

C$OPTIONS DEC,CCOMB=19
C PROGRAM NAME: STRESS
REAL DUMMY(24), OUT(6), X(15), L95(4), YOI(15)
REAL ROJ, AREA(15), DET, SUBJL, SUBJW, L1L2, W1W2, DELXXX(5)
REAL INER1, INER2, MASS, SIG(2), FORCE(6,1), MOMENT(3)
REAL A, B, C, CG(15), WEIGHT(15), INERT(45), DI(4)
REAL OMEGA(3), FJ(3), TJ(3), ALPHA(3), ACCEL(3), U2(3)
REAL POSIT(24), INSTRNT(6)
INTEGER SEG(8), CHECK(4), NCON, KCON, YES, RT6, J, K, NSEGS, NT, I
INTEGER ODD
EQUIVALENCE (DUMMY(1), FORCE(1)), (T, TEMP), (S2, TEMP, SUBJL)
EQUIVALENCE (A1, S1, SUBJW), (INER2, SUBJL)
COMMON /Q57/ FORCE
COMMON /Q6/ BONEP(8), BONEA(8), BONEI(8), L1L2, W1W2, A1, INER1,
S RORIG, INER2, RO
DATA L95 /18.89, 15.98, 11.02, 11.0 /
DATA SEG /'RUL', 'ELL', 'LUL', 'LLI', 'RUA', 'RLA', 'LUA', 'LLA' /
DATA GINCH / 386.0886 /, PI / 3.141593 /, W95 / 217.0 /
DET (A,B) = SQRT (A * A + B * B / 2.)
SIMAX = 0.0
S2MAX = 0.0
TMAX = 0.0
WRITE (8,5)
5 FORMAT (' INPUT SEGMENT # TO BE ANALYZED (INTEGER 1-777777) ')
DO 7 I = 1, 8
WRITE (8,6) I, SEG(I)
6 FORMAT ('H', I3, ' = ', A4)
7 CONTINUE
READ (1,*) J
NSEGS = 7
READ (5) NT, DLT, KCON4, (POSIT(I), I = 1, KCON4)
YES = 0
DO 8 I = 1, KCON4, 4
IF (POSIT(I) .NE. J) GO TO 8
YES = 1
GO TO 9
8 CONTINUE
9 FIND MASS, DI AND SEMI-MAJOR AXES OF SEGMENT J FROM FILE #5
9 READ (5) DI
IF (J .NE. 1) CALL FOR (J-1, 5)
READ (5) K, MASS, A, B, C
IF (J .NE. 8) CALL FOR (8-J, 5)
IF (K .NE. J) PRINT, 'LOOKING FOR SEGMENT FILE', J, ' FOUND', K
WRITE (3,150) J, SEG(J), NT, NSEGS
WRITE (3,155) MASS, A, B, C
IL = YES + 1
IR = YES + 3

```

AD-A112 456

DUKE UNIV DURHAM NC DEPT OF MECHANICAL ENGINEERING A--ETC F/8 6/19
DEVELOPMENT OF A STRAIN RATE DEPENDENT LONG BONE INJURY CRITERI--ETC(U)
JAN 82 T K MIGHT AFOSR-81-0062 NL

UNCLASSIFIED

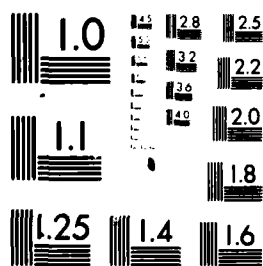
AFOSR-TR-82-0138

2 of 2
AD-A112 456



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2 OF 2
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A112458



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

	IF (YES .GT. 0) WRITE (3,156) (POSIT(I), I = 1, IR)	00000510
C	SET JNUM TO EQUAL PROPER COUNTER IN GEOMETRY FILE #5.	00000520
C	READ (3,*) CHECK	00000530
	GO TO (10, 20, 30, 40, 30, 40), J	00000540
10	JNUM = 1	00000550
	ODD = 1	00000560
	GO TO 50	00000570
20	JNUM = 2	00000580
	ODD = -1	00000590
	CALL FOR (CHECK(1), 6)	00000600
	GO TO 50	00000610
30	JNUM = 3	00000620
	ODD = 1	00000630
	CALL FOR (CHECK(1) + CHECK(2), 6)	00000640
	GO TO 50	00000650
40	JNUM = 4	00000660
	ODD = -1	00000670
	CALL FOR (CHECK(1) + CHECK(2) + CHECK(3), 6)	00000680
	GO TO 50	00000690
50	WRITE (3,157) DI(JNUM), L95(JNUM)	00000700
C	CREATE PERCENT-OF-LENGTH POINTS TO BE USED BETWEEN 20 & 80	00000710
C	SOLVE FOR NEEDED VALUES AT EACH FREE-BODY SECTION.	00000720
C		00000730
	VOL = 4. * PI * A * B * B / 3.	00000740
	RO = MASS / VOL	00000750
	A2 = A * A	00000760
	A3 = A * A2	00000770
	A4 = A * A3	00000780
	B2 = B * B	00000790
	B3 = B * B2	00000800
	WRITE (3,25)	00000810
	DO 60 I = 1, NSEGS	00000820
	K = 3 * I - 2	00000830
	DELX(I) = 0.20 * (ROAT (K) - 1) * 0.60 / BLOCK (NSEGS - 1)	00000840
	X(I) = DELX(I) * L95(JNUM)	00000850
C	XI WITH RESPECT TO C.G. OF FULL ELLIPSOID	00000860
C		00000870
	X1 = X(I) - DI(JNUM)	00000880
	X2 = X1 * X1	00000890
	X3 = X2 * X1	00000900
	X4 = X3 * X1	00000910
C	FIND WEIGHT (OR MASS) OF FREE-BODY SECTION I.	00000920
C		00000930
	WEIGHT(I) = RO * PI * B2 * (A2 * X1 - X3 / 3. + 2 * X3 / 3. * I / A2	00000940
C	FIND C.G. OF FREE-BODY SECTION I RELATIVE TO C.G. OF ELLIPSOID	00000950
C		00000960
		00000970
		00000980
		00000990
		00001000
		00001010

```

C      CG(I) = 3. * (2.*X2*A2 - X4 - A4) / (3.*A2*X1 - X3 + 2.*A3) / 4. 00001020
C      FIND I(XX) OF FREE-BODY SECTION I ABOUT POINT X(I) 00001030
C      TEMP = PI * RO * B2 * B2 / (2. * A4) * 00001040
C      $ (A4*X1 + X4*X1/5. - 2.*A2*X3/3. + 8.*A2*A3/15.) 00001050
C      INERT(K) = TEMP / GINCH 00001060
C      FIND I(YY) = I(ZZ) OF FREE-BODY SECTION I ABOUT POINT X(I) 00001070
C      TEMP = RO * PI * R2 * (X3* (1./3. - X2 / (30.*A2)) 00001080
C      $ + X1*B2/3. * PI - 2.*X2/(3.*A2) + X4/15.*A5)) 00001090
C      $ + 2. / 15. * (A3 + A*B2) + A2*X1/2. + 2.*X2*3/3. ) 00001100
C      INERT(K+1) = TEMP / GINCH 00001110
C      INERT(K+2) = INERT(K+1) 00001120
C      WRITE (3,450) I, XX, HEIGHT(I), CG(I), INERT(K), INERT(K+1) 00001130
C      60 CONTINUE 00001140
C      FIND AREAS AND INERTIA PROPERTIES -- USE DETAIL DATA IF 00001150
C      AVAILABLE (CHECK(JNUM) = +1) -- ELSE USE CONSTANT CROSS-SECTION 00001160
C      HOLLOW TUBE FOR BONE (CHECK(JNUM) = -1). 00001170
C      IF (CHECK(JNUM) .GT. 0) GO TO 80 00001180
C      CONSTANT CROSS-SECTION 00001190
C      READ (6,*1) A1, TEMP4, TEMPI 00001200
C      TEMP2 = TEMP4 * TEMP4 00001210
C      TEMP3 = TEMPI * TEMPI 00001220
C      A1 = PI * (TEMP3 - TEMP2) 00001230
C      TEMP = PI * (TEMP1 * TEMP1 - TEMP2 * TEMP2) / 4. 00001240
C      WRITE (3,160) TEMP4, TEMPI, A1, TEMP 00001250
C      TEMP = TEMPI / TEMP 00001260
C      DO 70 I = 1, NSEGS 00001270
C      AREKIT = A1 00001280
C      70 Y0I(I) = TEMP 00001290
C      GO TO 95 00001300
C      VARIABLE CROSS-SECTION KINSECTING TO 95TH PERCENTILE 00001310
C      80 READ (6,*1) SUBJL, SUBJW 00001320
C      K = CHECK(JNUM) - 1 00001330
C      DO 85 I = 1, K 00001340
C      85 READ (6,*1) BONEP(I), BONEA(I), BONEI(I) 00001350
C      K = I 00001360
C      LIL2 = SUBJL / L95(JNUM) 00001370
C      W95 = SUBJW / W95 00001380
C      WRITE (3,170) SUBJW, SUBJL, W95, L95(JNUM) 00001390
C      WRITE (3,175) 00001400

```

DO 90 I = 1, NSEGS	00001520
CALL INTERP (K, JNUM, DELX(I), AREA(I), VOI(I))	00001530
WRITE (3,180) DELX(I), X(I), AREA(I), INER2, RO	00001540
C4 WRITE (3,400) DELX(I), X(I), AREA(I), INER2, RO	00001550
90 CONTINUE	00001560
C4 STOP	00001570
C-----	00001580
C BEGIN MAIN LOOP FOR ALL TIME STEPS FOR LINE 1	00001590
C-----	00001600
95 DO I45 KK = 1, NT	00001610
C-----	00001620
C FIND APPLIED LOADS ON LINE 1 FROM FILE 15.	00001630
C-----	00001640
READ (5) TIME	00001650
IF (J.NE. 1) CALL FOR (J-1, 5)	00001660
READ (5) TIME, KT, NCON, OMEGA, F1, F2, ALPHA, ALCE, UZ,	00001670
\$ (DUMMY(1), I = 1, KT), (CNSTRN(1), I = 1, NCON)	00001680
IF (J.NE. 8) CALL FOR (8-J, 5)	00001690
WRITE (3,200) TIME	00001700
C1 WRITE (3,21) F1, F2, ALPHA, ALCE, OMEGA, UZ	00001710
C1 2 FORMAT (1H, 'APPLIED LOADS', 6F12.5, /, (15, 6F12.5))	00001720
KT6 = KT / 6	00001730
IF (KT6.EQ. 0) GO TO 96	00001740
WRITE (3,500) KT6, DUMMY(1), I = 1, KT, 61	00001750
C1 PRINT, (DUMMY(I), I = 1, KT)	00001760
C1 96 IF (YES.EQ. 0) GO TO 100	00001770
C1 PRINT, "OTHER CONSTRAINT FORCES"	00001780
C1 PRINT, (POSITIVE(I), I = 1, 10), (CNSTRN(I), I = 1, 10)	00001790
C-----	00001800
C BEGIN LOOP FOR EACH FREE-BODY SECTION I.	00001810
C CALCULATE STRESSES ON EACH FREE-BODY SECTION USING MOHR'S CIRCLE	00001820
C AND STATIC EQUILIBRIUM	00001830
C-----	00001840
100 WRITE (3,250)	00001850
DO I45 I = 1, NSEGS	00001860
RO1 = VOI(I) / 2	00001870
XFORCE = 0.0	00001880
DO 105 K = 1, 3	00001890
105 MOMENT(K) = 0.0	00001900
IF (YES.EQ. 0) GO TO 107	00001910
C-----	00001920
C FIND MOMENTS AND SUM FORCES DUE TO "OTHER CONSTRAINT FORCES"	00001930
C-----	00001940
XPOINT = XPT - POSITIVE(1)	00001950
IF (XPOINT) 107, 107, 106	00001960
106 MOMENT(1) = POSITIVE(2) * CNSTRN(3) - POSITIVE(3) * CNSTRN(2)	00001970
MOMENT(2) = XPOINT * CNSTRN(3) + POSITIVE(3) * CNSTRN(1)	00001980
MOMENT(3) = -XPOINT * CNSTRN(2) - POSITIVE(2) * CNSTRN(1)	00001990
XFORCE = CNSTRN(1)	00002000
107 IF (KT.EQ. 1) GO TO 120	00002010

	FIND MOMENTS & FORCES DUE TO CONTACTS	00002020
	DO 110 K = 1, KTB	00002030
	XPOINT = X(I) - FORCE(1,K)	00002040
	IF (XPOINT) 120, 120, 108	00002050
108	XFORCE = XFORCE + FORCE(4,K)	00002060
110	CALL XPROD (XPOINT, K, MOMENT)	00002070
	FIND TOTAL MOMENT, SHEAR STRESS & TENSILE STRESSES	00002080
	X2 IS DISTANCE FROM X(I) TO C.G. OF SECTION $F = DISTALY * MASS$	00002090
	120 X2 = (DI(JNUM) - X(I) + CG(I)) * WEIGHT(I)	00002100
	K = 3 * I - 2	00002110
2	IF (K) .GT. 1 WRITE (3,121) MOMENT, XFORCE	00002120
2121	FORMAT (' CONTACT MOMENTS', T25, 3F10.3, ' SUM XFORCE', F10.3)	00002130
	MOMENTS ABOUT Z-AXIS	00002140
	TEMP1 = INERT(K+1) * (U2(3) - ALPHA(3)) - MOMENT(3)	00002150
	5 - FJ(2) * X(I) - ACCEL(2) * X2	00002160
	MOMENT ABOUT Y-AXIS	00002170
	TEMP2 = INERT(K+1) * (U2(2) - ALPHA(2)) - MOMENT(2)	00002180
	5 + FJ(3) * X(I) + X2 * ACCEL(3)	00002190
	IF (MOD .LT. 0) TEMP2 = TEMP2 - FJ(2)	00002200
	MOMENT ABOUT X-AXIS (TORSION TORQUE)	00002210
	TORQUE = INERT(K) * (U2(1) - ALPHA(1)) - MOMENT(1)	00002220
	IF (MOD .LT. 0) TORQUE = TORQUE - FJ(1)	00002230
	T = SQRT (TEMP1 * TEMP1 + TEMP2 * TEMP2)	00002240
C2	WRITE (3,123) TEMP1, TEMP2, TEMP1, TEMP2, T	00002250
C2123	FORMAT (' MOMENTS (Z,Y,TOTAL)', T25, 3F10.3)	00002260
	TEMP1 = T * Y(I)	00002270
C	TOTAL AXIAL FORCE	00002280
	TEMP2 = ((WEIGHT(I) * ACCEL(1)) - XFORCE - FJ(1)) / AREA(I)	00002290
	SIG(1) = TEMP2 + TEMP1	00002300
	SIG(2) = TEMP2 - TEMP1	00002310
C2	WRITE (3,122) TEMP1, TEMP2, SIG	00002320
C2122	FORMAT (' BEND STRESS, FX, SI, SZ', T25, 4F10.3)	00002330
	TAU = TORQUE * RCJ	00002340
C2	WRITE (3,124) TORQUE, TAU	00002350
C2124	FORMAT (' TORQUE, SHEAR STRESS', T25, 2F10.3)	00002360
C		00002370
		00002380
		00002390
		00002400
		00002410
		00002420
		00002430
		00002440
		00002450
		00002460
		00002470
		00002480
		00002490
		00002500
		00002510

C	SOLVE MOHR'S CIRCLE FOR EACH END OF DIAMETER OF TUBE	00002520
C	DO 125 K2 = 1, 2	00002530
	K = K2 * RZ	00002540
	TEMP = DET (TAU, SIG(K2))	00002550
	TEMP2 = SIG(K2) / 2.	00002560
	SA = TEMP2 + TEMP	00002570
	OUT(K) = SA	00002580
	SB = TEMP2 - TEMP	00002590
	OUT(K+1) = SB	00002600
	TI = TEMP	00002610
	OUT(K+2) = TI	00002620
	125 CONTINUE	00002630
C	SI = AMAXI (OUT(1), OUT(4))	00002640
	S2 = AMINC (OUT(2), OUT(5))	00002650
	T = AMAXI (OUT(3), OUT(6))	00002660
	IF (SI .LT. SIMAX) GO TO 130	00002670
	SIMAX = SI	00002680
	XSI = X(I)	00002690
	130 IF (S2 .GT. S2MAX) GO TO 135	00002700
	S2MAX = S2	00002710
	XS2 = X(I)	00002720
	135 IF (T .LT. TMAX) GO TO 140	00002730
	TMAX = T	00002740
	XT = X(I)	00002750
	140 WRITE (3,300) DELX(I), XT(I), OUT	00002760
C9	WRITE (7,400) TIME, DELX(I), XT(I), OUT	00002770
	145 CONTINUE	00002780
	STOP	00002790
C	150 FORMAT (1H, 'STRESS HISTORY FOR SEGMENT #', I2, ' ', '83.7',	00002800
	\$ ' THERE ARE', I3, ' TIME STEPS', /,	00002810
	\$ ' 13, ' FREE-BODY SECTIONS WILL BE USED',	00002820
	155 FORMAT (1H, 'SEGMENT MASS =', F10.3, ' LBS.', /, 'SEMI-MAJOR AXES',	00002830
	\$ ' (X,Y,Z) ARE: ', 3F10.3, /,	00002840
	157 FORMAT (1H, 'PROXIMAL JOINT TO C.G. DISTANCE =', F10.2, ' IN.', /,	00002850
	\$ ' PROXIMAL JOINT TO DISTAL JOINT LENGTH =', F10.2, ' IN.', /,	00002860
	156 FORMAT (1H, 'OTHER CONSTRAINT FORCE' LOCATIONS', 3F10.3) /,	00002870
	\$ ' PROXIMAL JOINT TO DISTAL JOINT LENGTH =', F10.2, ' IN.', /,	00002880
	160 FORMAT (1H, 'BONE GEOMETRY -- CONSTANT CROSS-SECTION HOLLOW TUBE', /,	00002890
	\$ ' INSIDE RADIUS =', F6.3, ' IN.', /,	00002900
	\$ ' OUTSIDE RADIUS =', F6.3, ' IN.', /,	00002910
	\$ ' AREA =', F6.3, ' SQ. IN.', /,	00002920
	\$ ' 2ND MOMENT OF INERTIA =', F6.3, ' IN. ** 4.', /,	00002930
	170 FORMAT (1H, 'GEOMETRY DATA FOR THIS LIMB -- VARIABLE CROSS-SECTION',	00002940
	\$ ' HOLLOW TUBE', /,	00002950
	\$ ' BASED ON EXPERIMENTAL DATA: ', /,	00002960
	\$ ' SUBJECT: ', F7.0, ' LBS.', /,	00002970
	\$ ' F7.2, ' IN.', /,	00002980
	\$ ' 95TH PERC. MAN: ', F7.0, ' LBS.', /,	00002990
	\$ ' LIMB LENGTH =', F7.2, ' IN.', /,	00003000
		00003010

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175 FORMAT (IHO, I5, 'X', L, I13, 'X(IN)', T26, 'A(IN**2)', T39, 00003020
$ 'I(IN**4)', T51, 'OUTSIDE R. FINI'// 00003030
180 FORMAT (IH, F7.3, 4(F9.3, 5X)) 00003040
200 FORMAT (I, TIME = 'F12.5', SECONDS) 00003050
250 FORMAT (IHO, I5, 'X', L, I13, 'X(IN)', T29, 'S1', T39, 'S2', T48, 'TAJ T', 00003060
$ T64, 'S18', T73, 'S28', T82, 'TAU B'// 00003070
300 FORMAT (IH, F7.3, F9.3, 5X, 3F10.2, 5X, 3F10.2) 00003080
400 FORMAT (IH, 9F15.5) 00003090
425 FORMAT (IH, I4, I4, I12, 'X (FROM C.G.)', T29, 'MASS (LB)', T41, 00003100
$ 'CG (FROM C.G.)', T62, 'I(XX)', T72, 'I(YY) = I(ZZ)'// 00003110
450 FORMAT (IH, I3, 2X, 5F15.4) 00003120
500 FORMAT (IH, I1, 'CONTACT ICSETHS TIME STEP', 00003130
$ 'OCCUR AT X (FROM PROXIMAL) =', 4F6.2, //) 00003140
END 00003150
C. 00003160
SUBROUTINE XPROD (K, J, X, A2, YOI) 00003170
REAL A(3), B(6,4) 00003180
COMMON /Q57/ B 00003190
C 00003200
A(1) = A(1) + X * B(1,K) + B(4,K) * B(5,K) 00003210
C 00003220
A(2) = A(2) + X * B(6,K) + B(4,K) * B(3,K) 00003230
C 00003240
A(3) = A(3) + X * B(5,K) + B(4,K) * B(2,K) 00003250
C 00003260
RETURN 00003270
END 00003280
C. 00003290
SUBROUTINE INTERP (K, J, X, A2, YOI) 00003300
REAL L1I2, I1, I2 00003310
COMMON /Q67/ BP(8), BAT(8), BIT(8), L1I2, WIW2, A1, I1, RORIG, I2, 00003320
$ ROR 00003330
DATA PI /3.1415926/ 00003340
C 00003350
C FIND BOUNDING INTERVAL 00003360
C 00003370
DO 10 I = K, 6 00003380
IF (BP(I) .GT. X) GO TO 20 00003390
10 CONTINUE 00003400
20 IMI = I 00003410
C 00003420
C INTERPOLATE FOR VALUES OF AREA AND INERTIA 00003430
C 00003440
PERC = (X - BP(IMI)) / (BP(1) - BP(IMI)) 00003450
A1 = BA(IMI) + PERC * (BA(1) - BA(IMI)) 00003460
I1 = BI(IMI) + PERC * (BI(1) - BI(IMI)) 00003470
C3 PRINT, 'A1, I1', A1, I1 00003480
K = IMI 00003490
C 00003500
C FIND ORIGINAL OUTSIDE RADIUS FOR HOLLOW TUBE 00003510

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	00003520
	00003530
	00003540
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	00003570
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	00003740
	00003750
	00003760
	00003770
	00003780
	00003790
	00003800
	00003810

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SORT (2. * (A1 / 4. * PI * I1 / A1) / PI)
ORIGINAL OUTSIDE RADIUS, RORIG
TO 95-TH PERCENTILE SIZE
IW2 * LIL2 * RORIG / I1 * PI / 4.)
7 * WIR2 / PI
/ (X1 * Y1)
X1, Y1, Z1, XI, YI, ZI
(Z1 + SQRT(Z1 * Z1 + 8. * Y1)) / 4.
NEW OUTSIDE RADIUS, CROUL
OT * ROUT
QRT (SO - YI)
N * RIN
* (SO - XI)
* (SO * SO - XI * XI) / 4.
OUT / I2
A2, I2, YOI, A2, I2, YOI

INE FOR (K, IFILE)
IE, EQ, AT GO TO 200
= 1, K
FILE)

* 1, K
FILE, *)

```

